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SEPTEMBER, 1944

STRUCTURE OF SOUTH LOUISIANA DEEP-SEATED DOMES[1]

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ABSTRACT

This is primarily a study of the subsurface, geologic structure of oil fields in Louisiana within a coastal belt about 75 miles wide. For this report, 1,000 electrical logs of wells were studied; 123 were selected for reproduction in the cross sections. Most of the structures are the result of the rise of plastic salt columns from deep within the sedimentary layers of the earth's crust. The present depth of the top of the salt column determines the structural characteristics of the resulting domes.

This study is devoted particularly to the deep-seated domes in which salt has not been reached. Two common types of structures are found in this group.

The most common structural type consists of a region of domed sediments crossed by a series of normal faults creating a graben in the center of the domed layers. The graben of deep-seated domes is bounded by major faults. All observed grabens contain several faults, both major and minor, resulting in a complex mass of faulted blocks. Most of the major faults converge downward toward a zone believed to lie just above the head of the salt column. The dome-with-graben type of structure appears to be a fundamental type to which all of the others are related.

A less common type may be described as a dome offset by one or more major faults which have similar directions of strike and dip. In many such cases, it is believed that when additional wells are drilled, other faults will be found to complete a central graben.

No reverse faults were found. All of the structures contain normal faults. These faults may be broadly divided into major and minor types. Major faults characteristically increase in throw downward. The throws of major faults range from 100 to more than 900 feet. Observed dips of major faults range from 45° to 65°. The throw of these faults on any structure gives a rough approximation of the amount of structural relief.

Minor faults take only a minor part in the segmentation of the domes. Two distinctive types are recognized.

Radial minor faults extend radially from the center of doming.

Complementary minor faults are distinctive in that the throw decreases downward. Such faults create small grabens against major faults. Complementary faults relieve tension in the outer layers of the dome.

Other minor faults are less readily classified. They may be parallel and close to major faults or they may be branches or small divisions of major faults. In many, the throw is so small that they can not easily be traced.

The following theory is proposed to explain the development of the grabens. First, upward movement of a salt plug or column causes the deeply buried layers to be gently domed. Continued salt movement causes rupture in the form of a major, normal fault extending diagonally upward through the dome from the head of the salt plug.

Additional salt movement causes additional faults of the same kind but which in a general way are directed alternately opposite to, and parallel with, the first. The result is a complexly faulted

[1] Manuscript received, February 12, 1944. Published by permission of the Louisiana Geological Survey.

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graben, with the later faults at higher levels within the graben. Continued salt movement results eventually in a shallow salt dome.

The present distribution of oil and gas on deep-seated domes is the result of two sets of conditions. The present general location of the oil and gas is related directly to the center of the original gentle dome created by the earlier movements of the salt. Into this simple domal trap, petroleum migrated from the entire deformed area of the dome.

The specific location of each individual trap for each sand is now dependent on the segmentation of the dome by faulting. In general, the petroleum will remain in its original geographic location, but with many complications added by the barriers developed by faulting and the further tilting of faulted blocks.

Original maps and sections were prepared for the following fields: Barataria, Bateman Lake, Bayou Sale, Erath, Gibson, Gillis-English Bayou, Grand Bay, Grand Lake, Horseshoe Bayou, Lafitte, Lake Long, Lake Mongoulois, North Crowley, Roanoke, St. Gabriel, West Gueydan.

PART I. INTRODUCTION

ACKNOWLEDGMENT

In August, 1943, the writer completed a dissertation titled: "A Study of Deep-Seated Domes of South Louisiana." The information to be presented here represents a part of the material from this study. Since the aforementioned date it has been impossible to obtain the information necessary to keep up with drilling progress. Electrical logs, maps, and other information were obtained from the Louisiana Geological Survey. A more comprehensive report on deep domes is being prepared by this Survey.

The assistance of R. J. Russell and J. Huner, Jr., is gratefully acknowledged.

CLASSIFICATION OF SALT DOMES

The salt domes of south Louisiana may be divided into three groups on the basis of the depth to the top of the salt column (after Teas, 1935, pp. 694–96).

1. Shallow domes: depth of salt less than 2,000 feet
2. Intermediate depth domes: depth to top of salt between 2,000 and 6,000 feet
3. Deep domes: depth to top of salt 6,000 feet or more

For purposes of this study the deep domes (3) of Teas have been divided into two groups.

3a. Deep-seated salt domes: top of salt definitely encountered below 6,000 feet
3b. Deep-seated domes: several deep wells drilled but no salt encountered

The deep-seated domes represent the end members of the series of structures known as salt domes. The only evidence of salt movement appears as deeply buried faults in gently uparched strata. In south Louisiana the different salt-dome structures present an almost continuous, graded series of salt depths ranging from Avery Island (salt depth 16 feet) to Erath and Bayou Sale (salt depth unknown). The present condition of each of these structures must be directly related to the factors which prevented or promoted the upward penetration of the salt.

REGIONAL STRUCTURE

All of the structures mentioned in this study lie in a coastal belt, about 75 miles wide, extending from the Calcasieu River to the eastern coast of the Mississippi River delta. In this area the regional structure consists of a homocline of Cenozoic

sediments dipping gently gulfward. This homocline is part of the north flank of the Gulf Coast geosyncline. The regional strike roughly parallels the present coastline. Surface beds have dips which are so slight as to be practically imperceptible. Dips rapidly increase to 20–30 feet per mile at depth and in some places, to as much as 150 feet per mile at depths below 6,000 feet. The regional southward dip is attributed to the depression of the region resulting from sedimentary loading, which has been more or less continuous since the beginning of the Cretaceous. This depression and regional flexing is believed to be in progress at the present time. Articles bearing on Gulf Coast structure have been reprinted from the *Bulletin* of the American Association of Petroleum Geologists in the book *Gulf Coast Oil Fields*, 1936 (particularly "Gulf Coast Geosyncline," Barton *et al.*, 1933).

STRATIGRAPHY

Silts, sands, clays, and gravels of Recent and Pleistocene age extend downward from the surface to depths which, in some places, exceed 3,000 feet (Howe, 1933, p. 651).

The Pleistocene gravels rest unconformably on a series of sands and sandy shales of Miocene age. The lower part of the Miocene (also called the "Middle Oligocene") begins with a rather distinct break into a section in which shales predominate, with minor sand bodies and a few coralline limestones. This part of the section contains the *Discorbis*, *Heterostegina*, and *Marginulina* zones. A regional structure map contoured on the highest occurrences of *Heterostegina* has been published by Lockwood (1940). The sands in the lower part of the Miocene furnish the greater part of production of this area.

The Vicksburg (Oligocene) is reached in a few fields along the northern edge of the area. In south Louisiana it consists almost entirely of shale and is therefore not productive.

As the principal interest of this study is structural, stratigraphic considerations arose only for purposes of correlation and, therefore, are purely incidental.

CHARACTERISTICS OF DEEP-SEATED DOMES

All of the structures studied contain one or more normal faults. In most of these structures, the faults are arranged so that they form a graben which is located in the approximate center of a gently domed region. The typical graben is not simple. It is complex, with one or more extra, flanking fault blocks. The location of the graben directly above the top of the salt plug on the Lake Mongoulois deep-seated salt dome suggests that deep domes have a central vertical axis around which the various structural elements are arranged in a more or less symmetrical pattern. This axis passes vertically through the salt column, through the center of the graben, and through the center of thinning of the sediments above.

The principal structural elements of grabens are determined by major normal faults with throws of several hundred feet.

Knowledge of the areal extent of structural deformation is limited necessarily

by the distribution of wells, since most of these wells are located near the center of doming.

Most indications of uparching and faulting appear to die out within the Miocene sediments, or in the unconformity above.

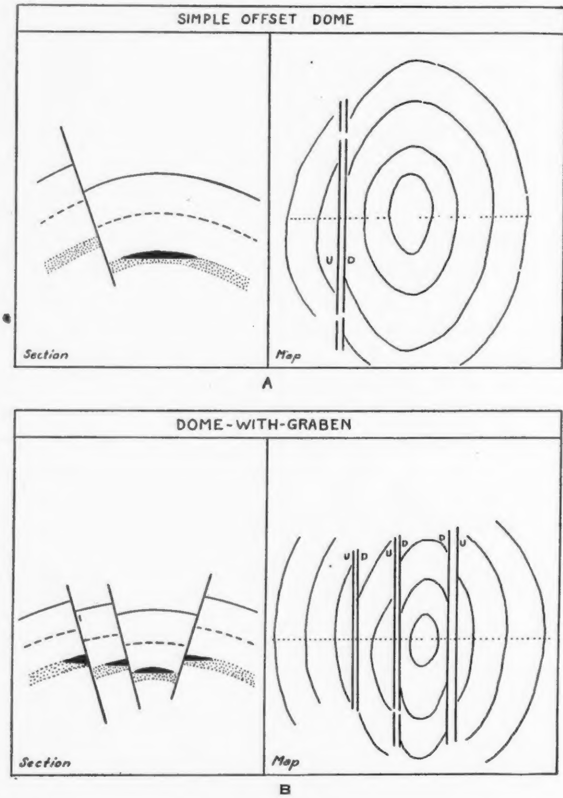


FIG. 1.—Fault patterns.

FAULT PATTERNS

Simple offset domes (Fig. 1A).—This type is well known from the report of Bornhauser and Bates (1938) on the Tepetate field. The producing area is located in the center of a gently domed structure on the downthrown side of a normal fault having several hundred feet of throw. Little or no production is expected from the flanking strata on the higher, upthrown side of the fault. The Erath dome[3] is a good example of this type.

[3] See Part II.

The simple offset dome classification must be regarded as provisional for any structure. Subsequent exploration may lead to the discovery of new faults which would complete a graben.

Dome-with-graben (Fig. 1B).—The most common, and at the same time, the most striking variety of structure is the dome bisected by a central graben, which ordinarily consists of several blocks at different levels. All grabens studied show evidence of a complex or compound fault pattern.

The faults which bound the graben converge at depth into a confused region of small faulted blocks. It was suspected from some of the first examples studied that the converging faults might lead to a small horst block resting on the crest of the salt. No horst of this kind has been identified. In many cases, the deeper wells show the faults converging, but fail to provide a clear indication of any junction. Wells rarely penetrate this critical zone to sufficient depths.

In typical structures there are three or more prominent faults with approximately parallel strikes but with one or more of these dipping in a direction opposite to the other faults. Subsurface contours on individual layers sweep in arcs which indicate doming. The flanks dip away gently from the faulted area. The displacement of structural contours along faults indicates angular truncation, or structural offset of part of the domed structure.

Examples of the dome-with-graben type in Louisiana include: St. Gabriel, Bateman Lake, Lafitte, Roanoke, and Gillis-English Bayou.[4]

Several structures have pairs of faults with similar strikes and dips but with no opposing faults to complete grabens. It is believed that further exploration will reveal the opposing faults which bound the graben. Grand Bay and Grand Lake are of this type.[5]

A number of facts regarding graben structures are difficult to explain. The most outstanding problem is why the graben, which consists of a downthrown block, is supposedly located directly above a salt mass which is known to have risen to its present position. How could a graben descend as a result of the rise of the salt beneath? Since any discussion of a mechanism capable of explaining this paradox is a matter of theory, it is discussed in detail in a later section of this article.

In graben structures, the oil may be trapped in the uplifted blocks against the principal faults on their upthrown sides. The downthrown blocks within the graben ordinarily produce against one of the bounding faults. If a block has been tilted in faulting, the oil is commonly found to have migrated to the highest part of the block. The general occurrence of oil and gas in various parts of the graben is most easily explained by considering that accumulation occurred in the dome before faulting took place. Otherwise, there appear to be insufficient drainage areas to account for the oil present in small blocks.

[4] See Part II.

[5] *Ibid.*

RELATION OF FAULTING TO STRUCTURAL RELIEF

Because of the concentration of wells in the higher parts of the structure, in the presumed vicinity of the vertical structural axis, little is ever known about the total actual uplift of any domed area. This varies with different layers, ordinarily increasing with depth. It is particularly important economically, in relation to drainage areas that contributed to the producing sands.

As the total uplift is directly related to the throw of the faults, an approximate value of structural relief can be obtained from a study of the faults. In the case of the graben, the central block has probably not been lifted much above the level which it occupied at the crest of the gentle dome which preceded faulting. The

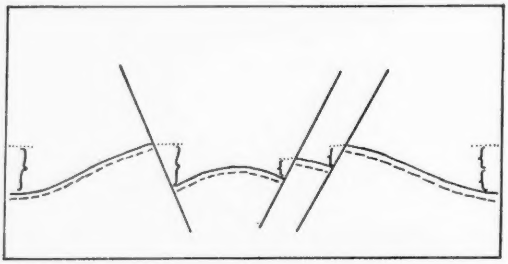


FIG. 2.—Relation of throw to structural relief.

present dip of the upthrown flanks beyond the graben is believed to have resulted principally from the faulting. It has been noted on many of the graben structures that opposite outer blocks rise to about the same level. This suggests that the force responsible for uplift is as effective on one side of a graben as on the opposed side. Where this relation holds, the minimum value for structural relief is the vertical distance the upthrown flanking blocks have been elevated.

Although this is a rather crude basis for estimating actual uplift, it is probably more reliable than comparison with some distant wildcat well, the exact structural position of which is unknown. Many wildcat wells should be considered as "prejudiced observers," because they are usually drilled where some structural relief has been suspected.

Where the total throw differs on opposite sides of a graben, the greater is nearer the actual relief. Faulting should not only be a measure of structural relief, but with greater relief, the total deformed area should also be greater. A larger structure, with faults having greater throws should have a larger drainage area.

PART II. EXAMPLES OF DEEP-SEATED DOMES

Fields are described in the order of their apparent complexity. The accompanying maps are simplified in order to emphasize the structural pattern. Wells are

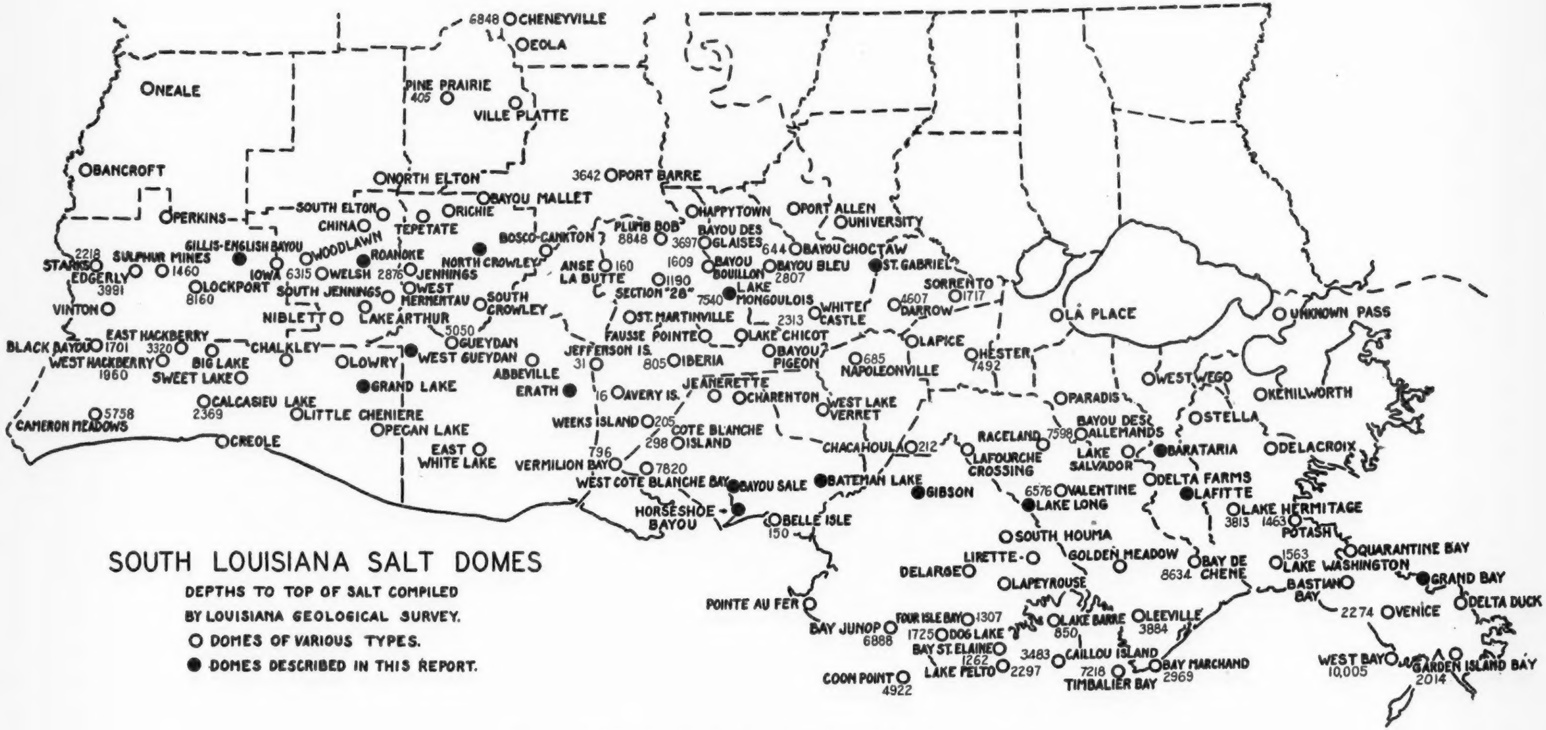


FIG. 3.—Index map showing location of south Louisiana salt domes.

indicated by small circles, whether productive or not. Circles with a dot on either side (·o·) indicate that no datum point could be obtained from that particular well. On the maps, faults are indicated by a pair of parallel lines. The distance between these lines is approximately equal to the heave of the fault. Broken lines indicate that the strike of the fault is not definitely known. The faults are identified on the maps and on the sections by corresponding numbers (F_1, F_2, *et cetera*). The upthrown block is marked "U" and the downthrown "D".

On the sections, the wells are numbered from left to right. On the maps a thin

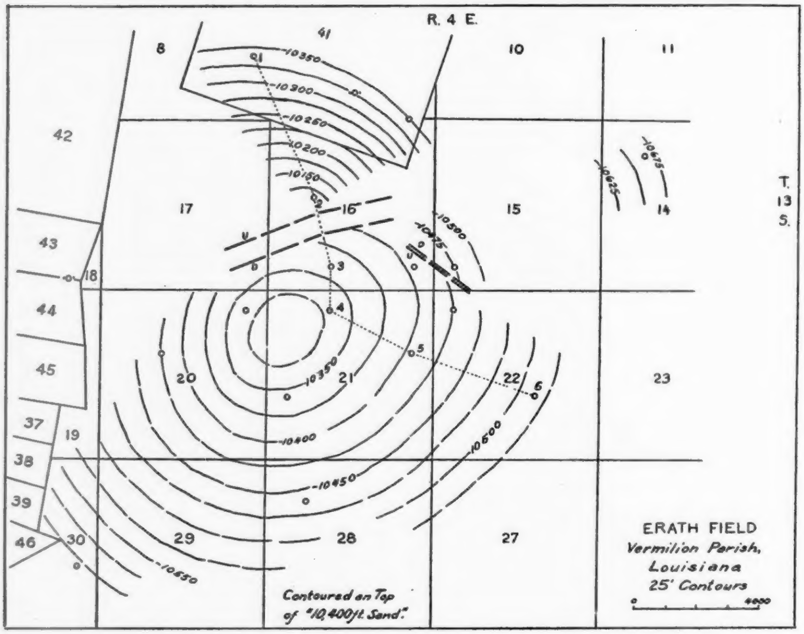


FIG. 4.—Erath field, Vermilion Parish. Wells numbered in cross section: (1) Phillips Petroleum Company's Cald No. 1; (2) Humble Oil and Refining Company's Vermilion Parish School Board No. 2; (3) and No. 1; (4) The Texas Company's A. Broussard No. 2; (5) and No. 1; (6) The Texas Company's A. Trahan No. 1.

dotted line indicates the line of the section. Numbers on the maps correspond with numbers on the sections. An accompanying list gives the name of the lease and company for each of the wells in the sections.

In many cases, the contoured horizon has no particular name or designation. However, the contours indicate its approximate depth in wells. On the cross sections, the contoured horizon may be identified by the unbroken line which connects electrical correlation points. Other correlations are represented by broken lines.

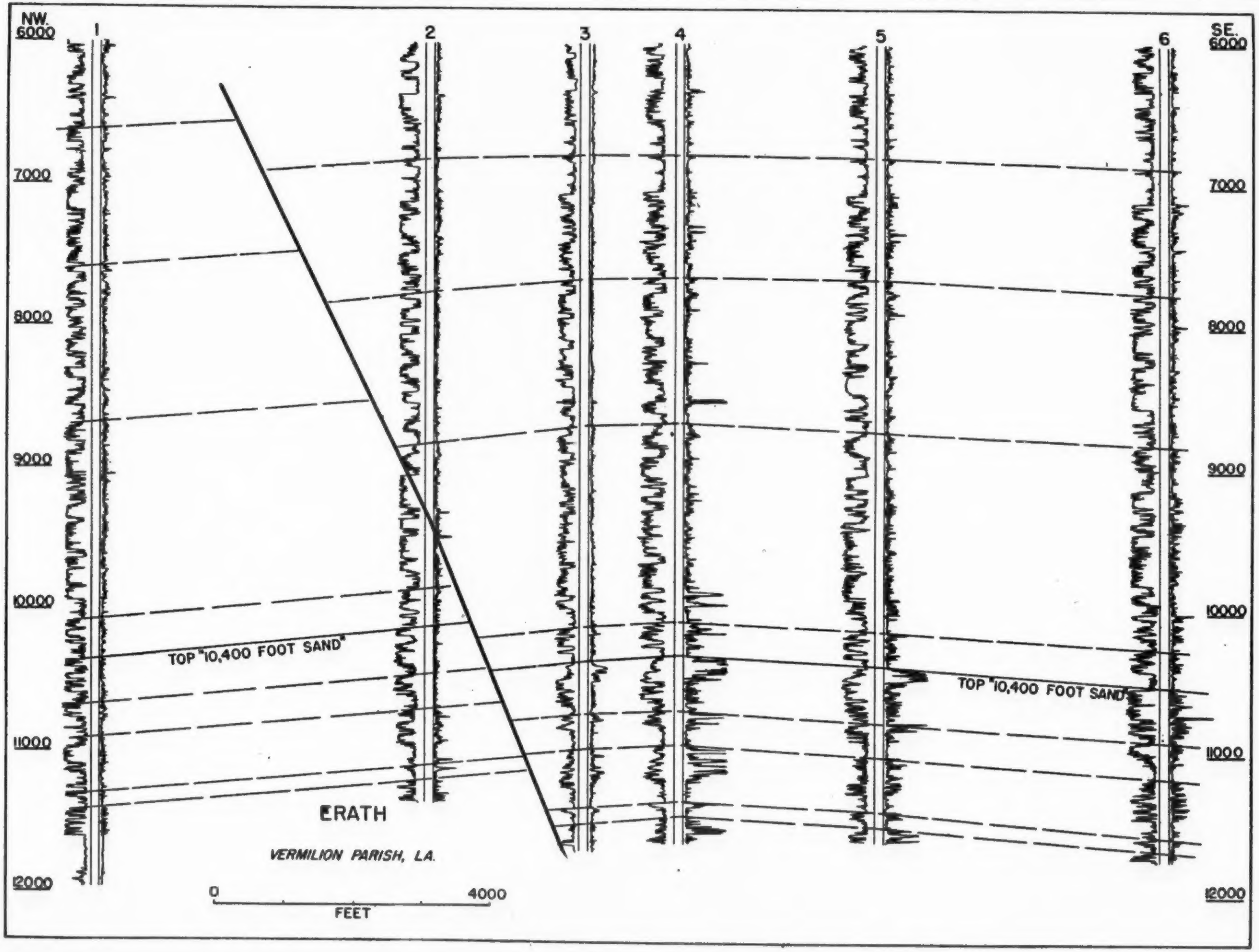


Fig. 5.—Electric-log cross section of Erath field.

ERATH FIELD, VERMILION PARISH

This structure was located in 1936 as a result of reflection-seismograph surveys carried out for The Texas Company, the Drunella Oil Company, and the Tide Water Associated Oil Company (*Oil Weekly*, March 16, 1942, p. 130). The area was covered by torsion balance for the DeSoto Oil Company in 1938. The discovery well was completed by The Texas Company in April, 1940. There are about sixteen possible producing sands, all Miocene in age. No salt or dome material has yet been found to a total depth of about 12,000 feet.

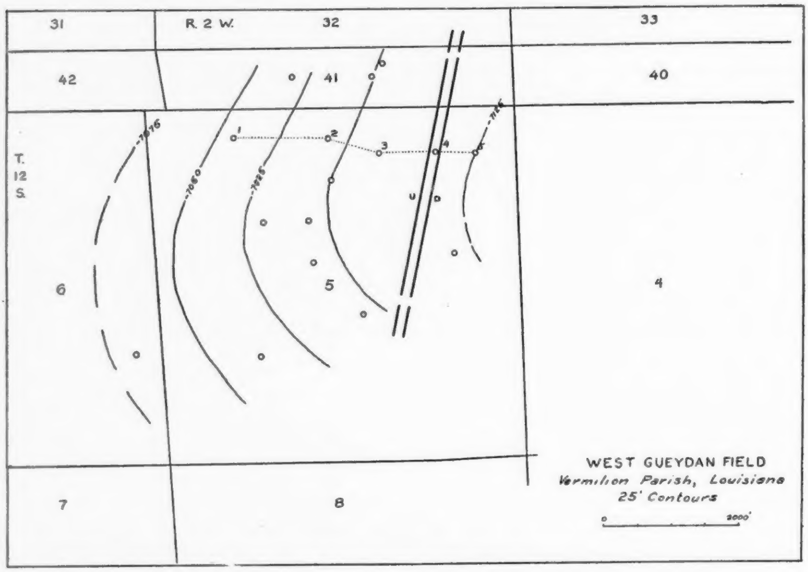


FIG. 6.—West Gueydan field, Vermilion Parish. Wells numbered in cross section (all Magnolia Petroleum Corporation): (1) A. Cormier No. 1; (2) J. B. Ferguson No. 1; (3) J. B. Ferguson No. 5; (4) H. Reese No. 2; (5) H. Reese B-1.

The subsurface structure on the top of the "10,400-foot" sand consists of a dome about 4 miles in diameter crossed by a large normal fault. The total structural relief is approximately 550 feet as measured between well No. 2 (in the section) and the well in Section 14. On this sand, the fault trace is about ½ mile north of the center of uplift. On the north flank the dips are considerably steeper: 225 feet per mile as against 150 feet per mile on the south flank. The steeper dips on the north upthrown block of the fault are believed to be evidence of the direct effect of the upward thrust of the salt against the upthrown block. The indirect effect on the south downthrown block is indicated by lesser dip.

The dome is offset by a single major fault with a measured throw of more than 400 feet. The maximum throw is probably 500 feet, which is approximately equal to the observed amount of total structural relief. The major fault strikes approximately northeast and dips south.

A single minor fault was found crossing the southwest corner of Section 15. It has a throw of about 40 feet and dips northeast.

Production of oil, distillate, and gas is possible from many sands below the 8,000-foot level. The major fault crosses the structure near its center of uplift which makes it possible for oil to be produced from both the upthrown and downthrown sides. The south, downthrown block has a much greater productive area.

This structure is very similar to the Tepetate structure, and may be classed as of the simple offset dome type. It resembles Tepetate not only in general structural features, but also in similar orientation of the major fault.

WEST GUEYDAN FIELD, VERMILION PARISH

This structure was located by a reflection-seismograph survey carried out for the Magnolia Petroleum Company in 1935 (*Oil Weekly*, March 16, 1942, p. 130). Several other companies explored the area with torsion balance. The discovery well was completed in July, 1938. The producing sands are Miocene in age. No salt or dome material has been discovered to a depth of 11,002 feet.

The subsurface structure between the 7,000- and 8,000-foot levels consists of the west half of a gently domed area bounded on the east by a north-striking fault upthrown on the west. The throw of the major fault increases gradually downward to a maximum of about 175 feet. The throw of this fault indicates that the total structural relief is probably more than 175 feet. Less than one third of the dome has been explored.

All the producing sands are located on the west upthrown side of the fault. The closure results from the fault seal on the east and the gentle dip of the sands toward the west. Additional oil will probably be found a short distance east of the present field.

Classification of this structure is uncertain on the basis of the information so far available. The most similar example is the Barataria dome, which is a simple offset dome producing from the upthrown side of a single fault. It is quite possible that additional wells on the east will find west-dipping faults to complete a central graben.

BARATARIA FIELD, JEFFERSON PARISH

This structure was outlined in 1939 by a reflection-seismograph survey carried out for the California Company (*Lockwood's Report*, 1940, p. 37). The first producing well was completed in November, 1939. Miocene sands are productive at the following levels: "7,600-foot," "8,200-foot," "8,700-foot," and "10,000-foot." The tops of these sands are indicated on the cross section. There are several wells which were directionally drilled from barge locations. Vertical and hori-

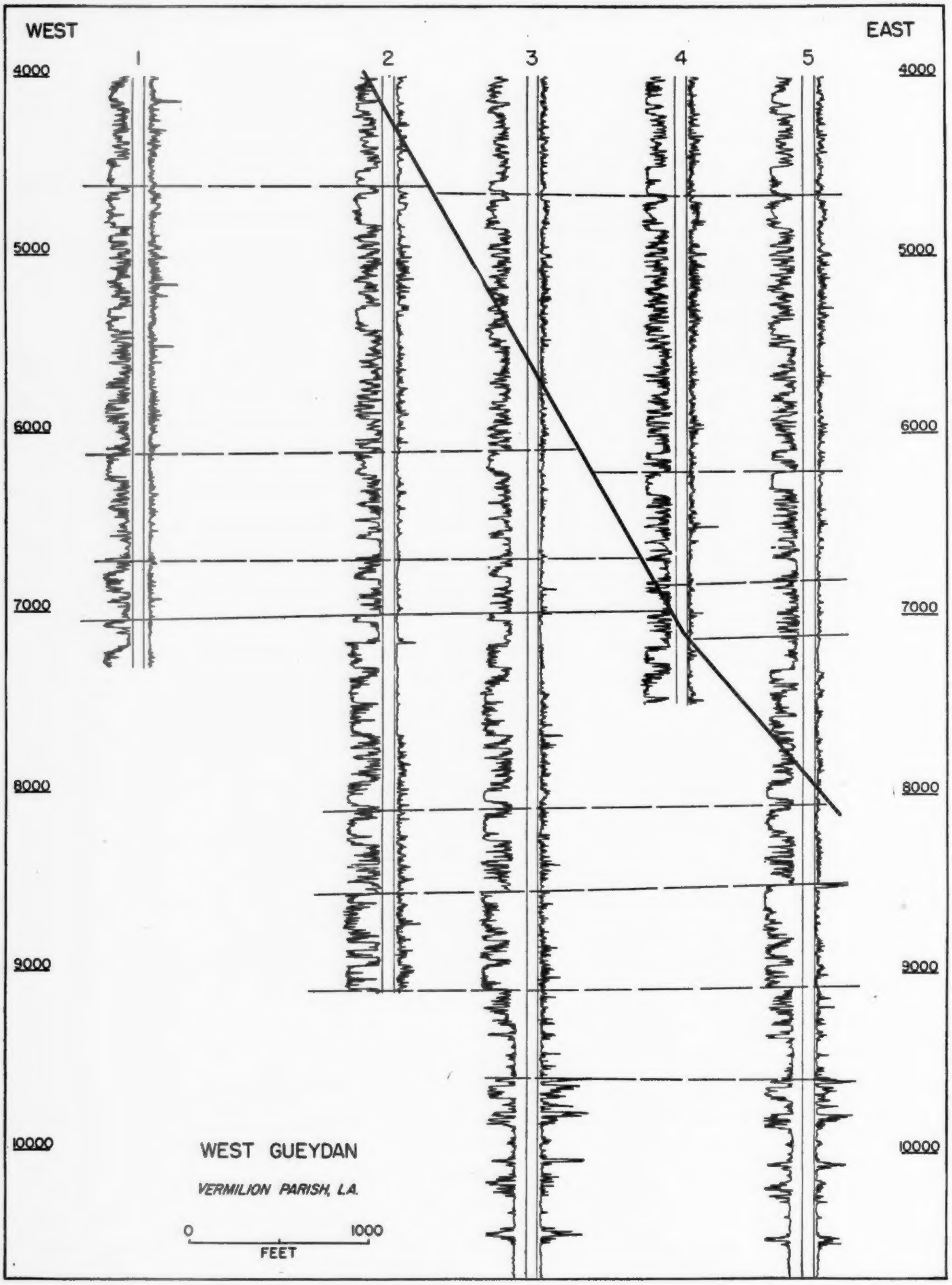


FIG. 7.—Electric-log cross section of West Gueydan field.

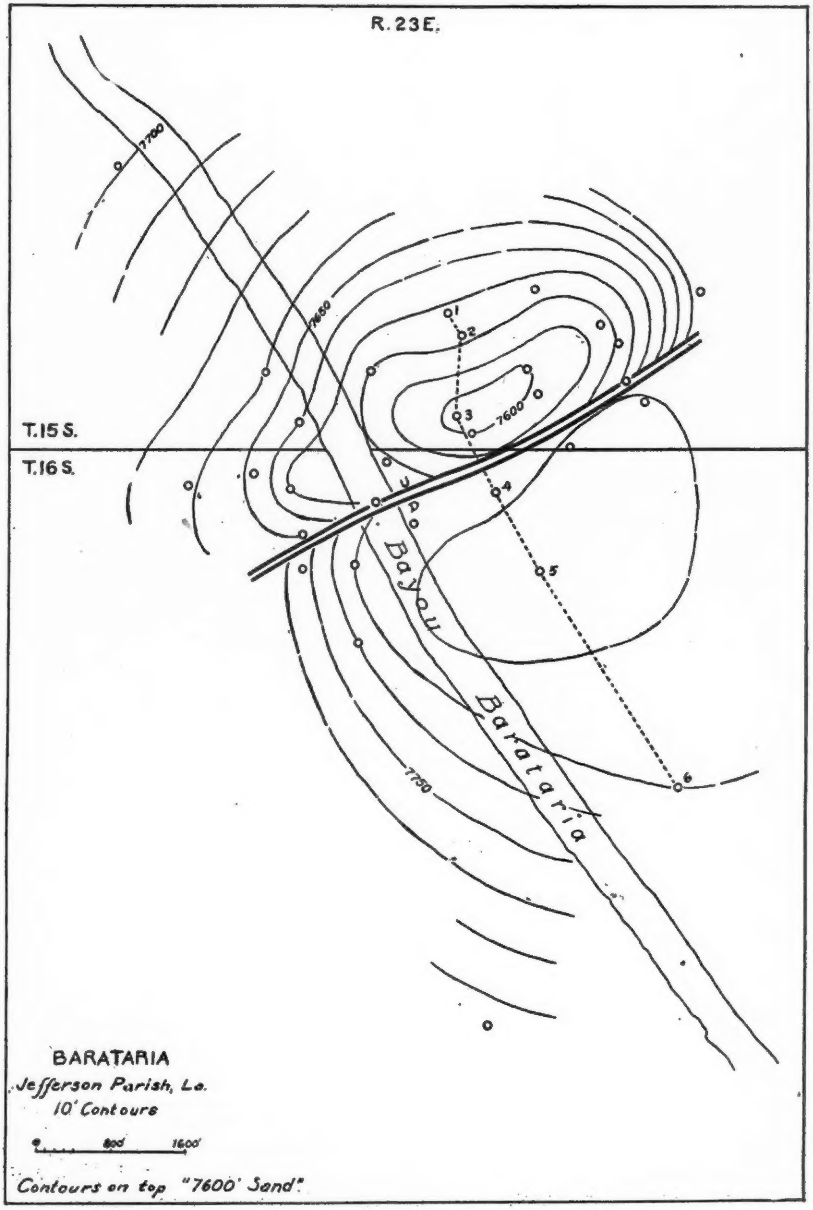


FIG. 8.—Barataria field, Jefferson Parish. Wells numbered in cross section (all California Company's Fleming Plantation): (1) A-14; (2) C-14; (3) No. 1; (4) No. 5; (5) No. 7; (6) No. 167.

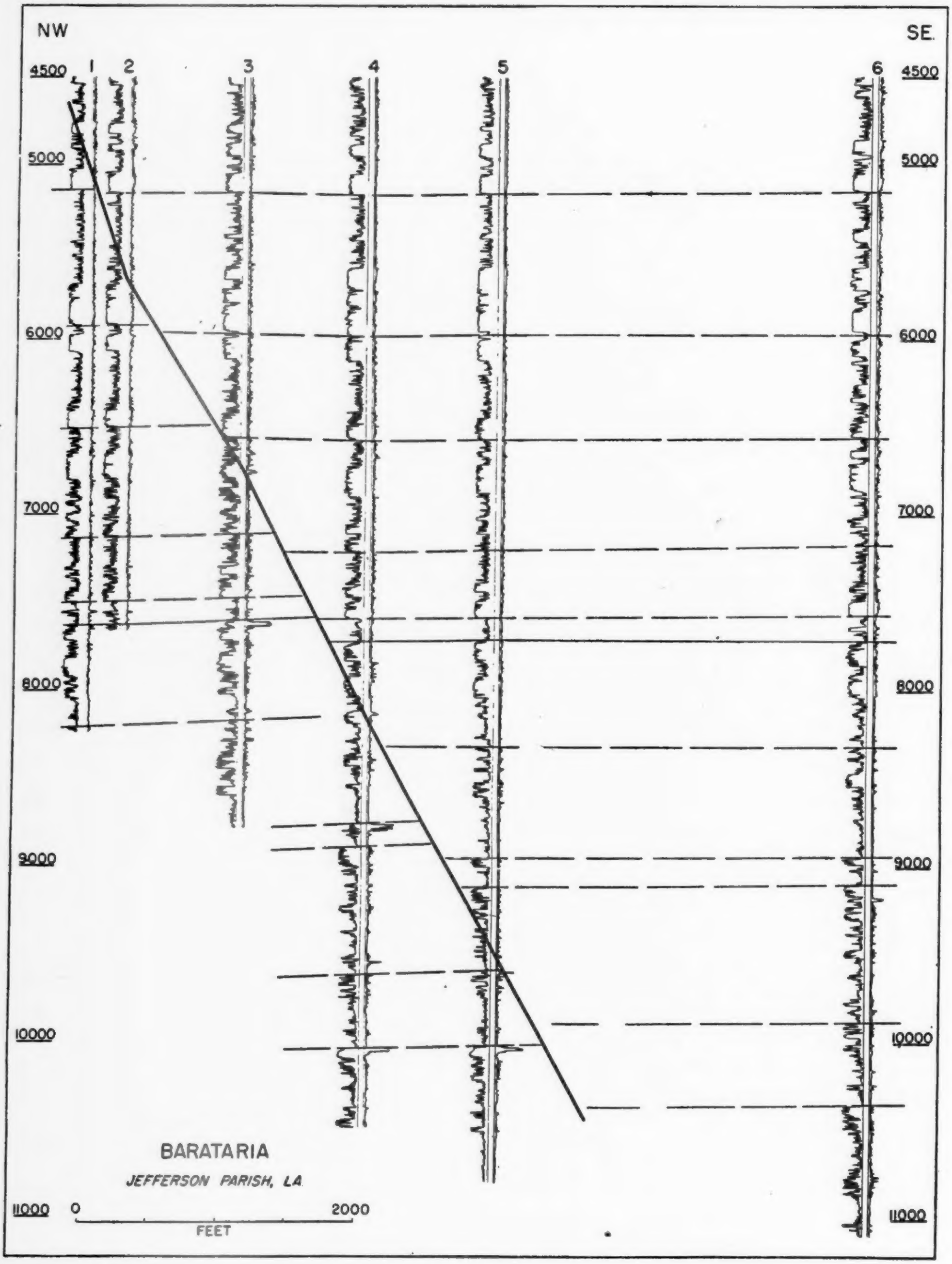


FIG. 9.—Electric-log cross section of Barataria field.

zontal corrections have been made for each. No salt was found to a depth of 12,222 feet.

The subsurface structure between the 7,000- and 8,000-foot levels is a broad gentle dome crossed by a northeast-striking normal fault. The north half of the dome lies on the upthrown side of the fault and is about 80 feet higher structurally than the south half. Graphic calculations of dip of the fault plane gave values ranging from 55° to 63°, with an average of 59°. The strike of the fault derived from graphic 3-point problems is slightly sinuous as shown on the accompanying map, varying from N. 86° E. to N. 51° E. The throw of the fault increases downward. Along the line of the section the following displacement values were observed.

Depth in Feet	*Throw in Feet*
5,500	40
6,750	110
8,350	150
9,150	220

There is also a noticeable amount of decrease in throw horizontally in both directions from the center of the field. There is a strong tendency for the north uplifted half to show an elongation parallel with the major fault. Judged by the throw of the fault, the structural uplift of the dome must be greater than 200 feet at the 9,000-foot level. No minor faults were observed.

Oil is produced entirely from the half of the dome on the north upthrown side of the fault which provides closure along the fault plane. The producing sands dip gently north away from the fault. Since the oil is reached by passing through the fault plane, some of the wells producing from the deeper sands are seen to be located south of the fault trace as located on the "7,600-foot" sand.

This structure, although of very simple form, is not readily fitted into a classification of deep-seated structures. In simplest form it may be described as a simple offset dome, but it differs from such typical examples as Tepetate in having production from the upthrown side of the principal fault. In this respect, it is similar to Grand Lake, which is complicated by at least three faults. If additional faults on the south should be found, the south, downthrown block of the present structure would lie in the graben. In any case, the small size of the single fault and the lack of additional faults suggest that the salt lies very deeply buried below. That a north-dipping fault might exist beyond the southernmost wildcat well is possible since the largest graben found in this study was 4 miles wide.

The elongation of the closure and the low relief suggest that the accumulation is a result of the north dip of the sediments which is a secondary feature due almost entirely to faulting.

GRAND LAKE FIELD, CAMERON PARISH

This prospect was outlined in 1935 by a reflection-seismograph survey carried out for the Pure Oil Company (*Lockwood's Report*, 1940, p. 135.) The discovery well was completed in May, 1939. There are at least four productive sands of Miocene age. At the present time, production is divided between the Superior

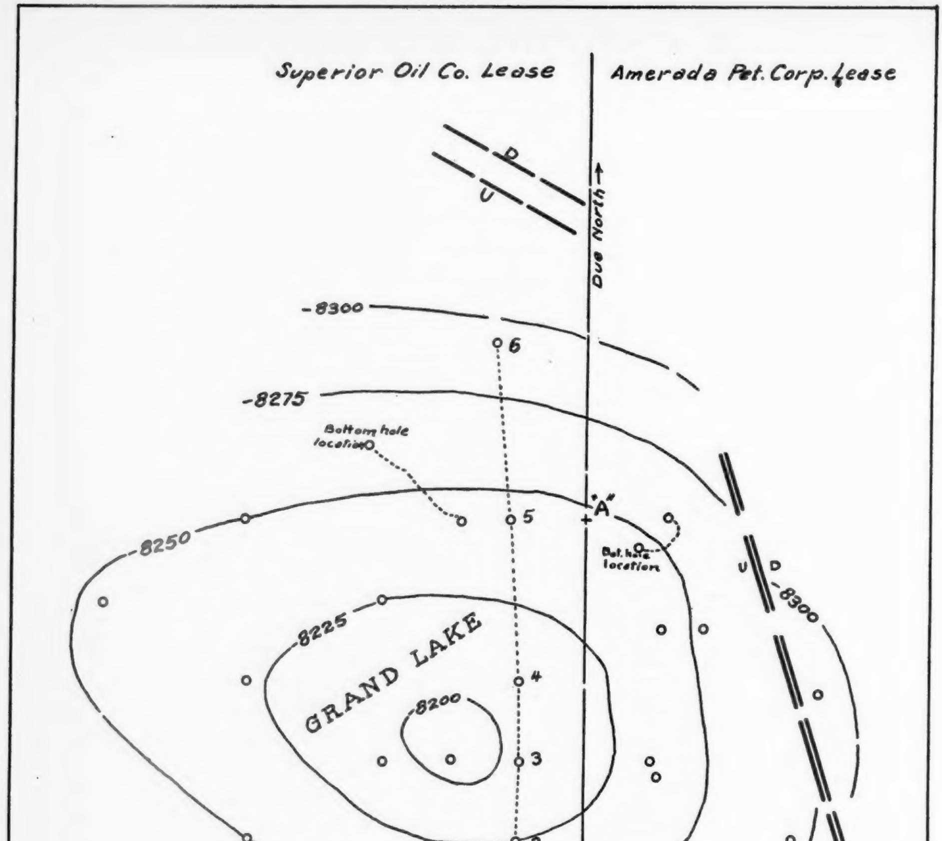


FIG. 10.—Grand Lake field, Cameron Parish, Wells numbered in cross section (all Superior Oil Company's Grand Lake State): (1) No. 10; (2) No. 8; (3) No. 14; (4) No. 4; (5) No. 5; (6) No. 3.

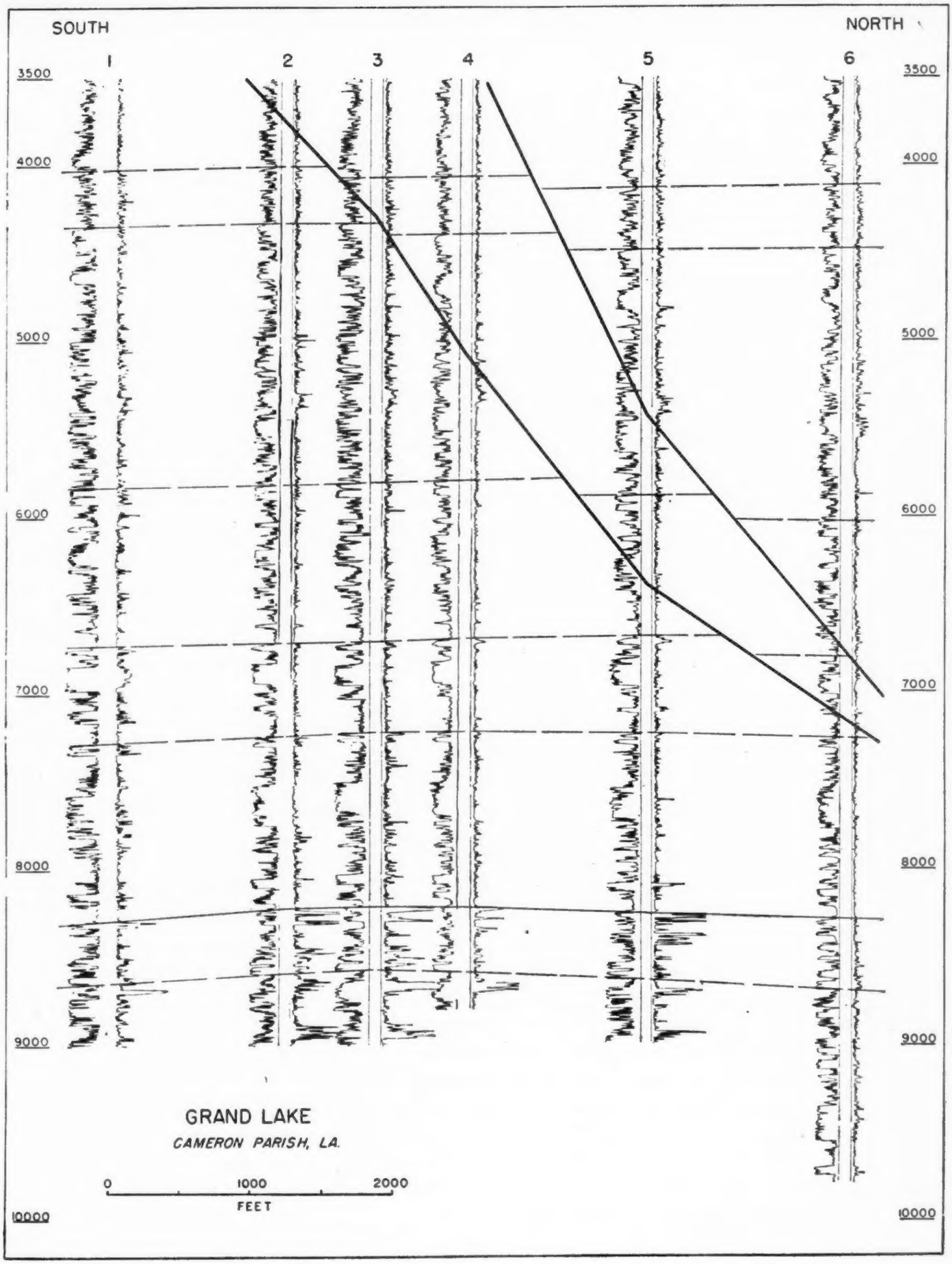


FIG. 11.—Electric-log cross section of Grand Lake field.

Oil Company and the Amerada Petroleum Corporation. The entire productive area is located beneath the waters of Grand Lake. No salt has been reached to a total depth of 11,384 feet. On June 1, 1943, there had been drilled a total of 25 wells, of which only one (No. 6 in the section) was not productive.

The subsurface structure between the 8,000- and 9,000-foot levels consists of a simple, gentle, slightly elongate dome with a slightly longer northwest-southeast axis. A minor fault with a throw of about 40 feet, downthrown toward the east, crosses the east edge of the field. The domed area is steepest on the south flank.

Above the 7,000-foot level there are a pair of major faults which cross the structure with a general northwest strike. Both are downthrown toward the north. These faults appear to divide at times, and to show a general convergence at depth. The maximum displacement for each appears to be about 100 feet. On the map these have been projected down to the level of the contoured sand and shown as a single fault with a throw of about 200 feet. In both faults, the throw gradually increases with depth. The total structural relief, as indicated by the combined throw of the major faults, would be in excess of 200 feet.

The structure can not readily be classified, although it is apparently simple so far as it has been explored. It is possible that other southward-dipping faults will be found on the northeast to complete a graben. In this connection it may be pointed out that the Mallard Bay prospect (Howe, Russell, and McGuirt, 1935, pp. 11, 205, 212, 175, 176) is located about 3 miles northeast of the Grand Lake field. Additional exploration may reveal the Mallard Bay prospect to be the northeast upthrown flank of the Grand Lake structure lying northeast of a central graben.

At Grand Lake, the closure is a result of doming rather than faulting, since there is a barren area between the fault and the edge of production. In any case, the salt appears to be at a considerable depth below the deepest wells, and the more important characterizing features of this structure lie beyond the limits of the present wells.

GIBSON FIELD, TERREBONNE PARISH

This structure was discovered in 1936 by the Barnsdall Oil Company and the Shell Oil Company using the reflection seismograph (*Oil Weekly*, March 16, 1942, p. 128). The producing area, about one mile northeast ("North Gibson" or "Northeast Gibson"), was located at the same time. The first producing well was completed in February, 1937. The first producing well in "Northeast Gibson" was completed in August, 1941. There are a number of producing sands of Miocene age. No salt has been found to a maximum depth of 11,350 feet.

This structure can not be readily compared with the more typical varieties of deep domes. There are apparently three small domed areas of closure. There are two faults, both of which strike northwest and dip southwest. Both have approximately equal throws, the maximum being about 75 feet. Each provides part of the closure for a productive area on its northeast, upthrown side. The maximum measurable structural relief is about 100 feet.

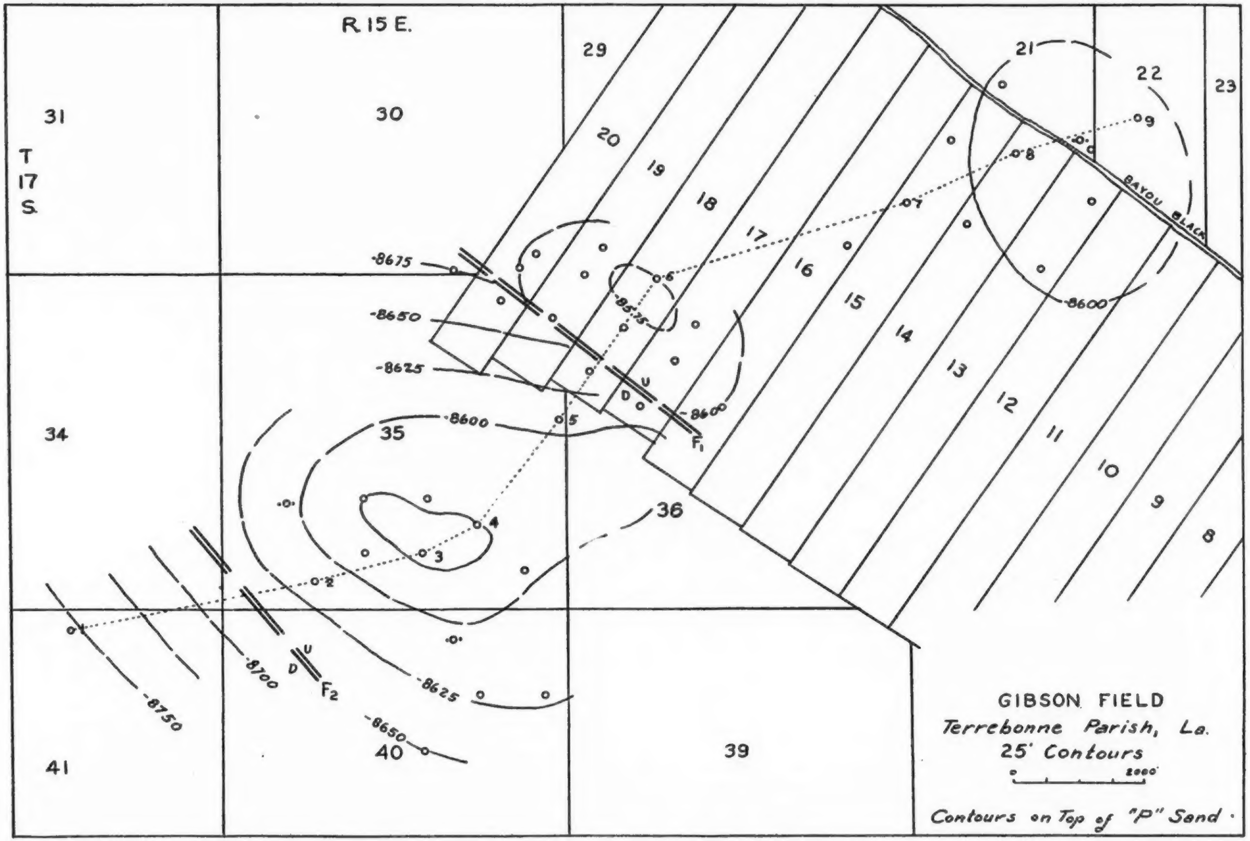
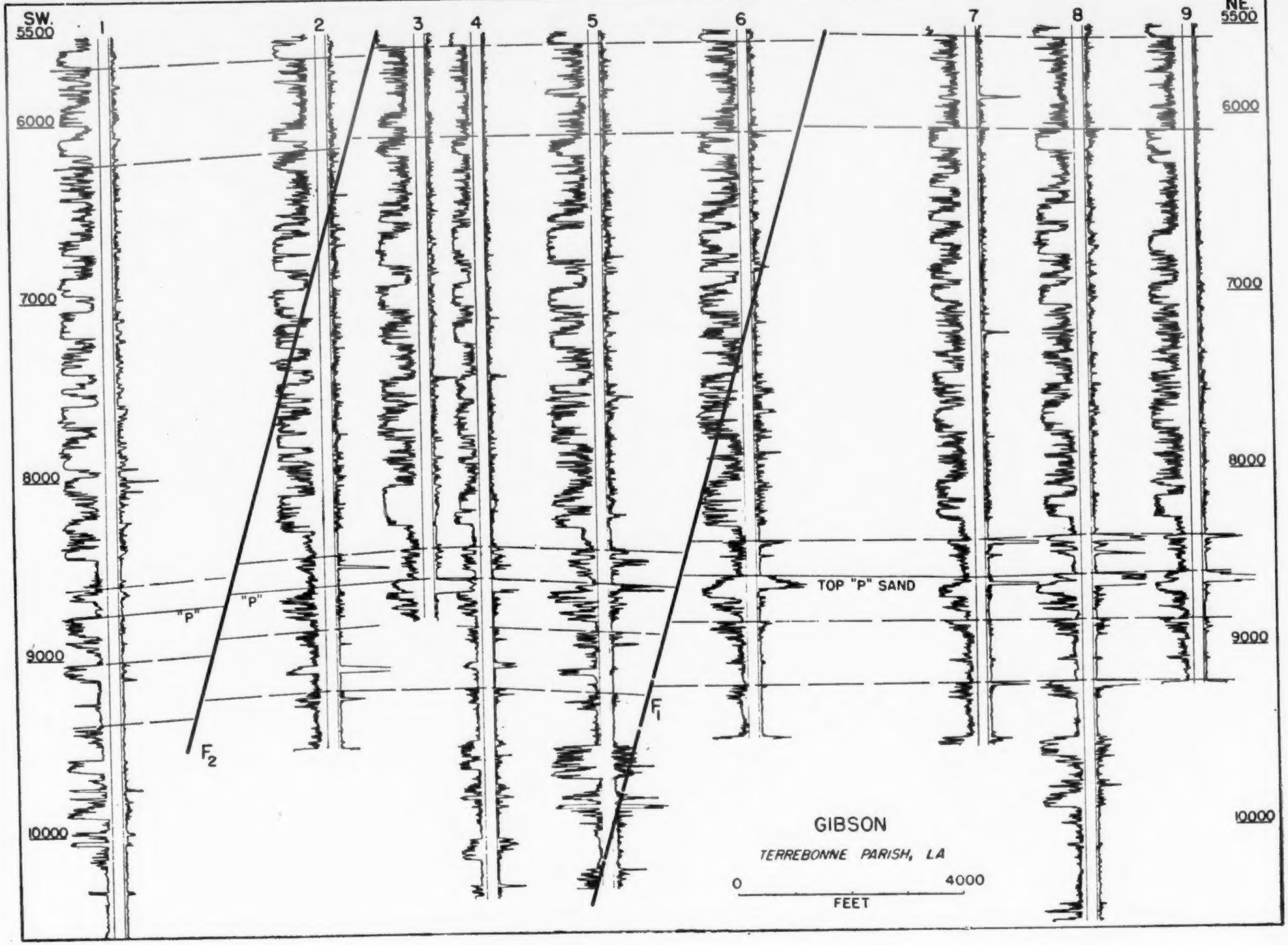


FIG. 12.—Gibson field, Terrebonne Parish. Wells numbered in cross section: (1) Shell Oil Company's R. E. K. No. 6; (2) Shell Oil Company's R. E. K. No. 5; (3) Shell Oil Company, Inc., Pelican No. 10; (4) Union Producing Company's Pelican A-1; (5) Shell Petroleum Corporation's Pelican No. 1; (6) Shell-Barnsdall's Realty Operators B-3; (7) Shell Oil Company, Inc., Realty Operators B-12; (8) Shell Oil Company's Realty Operators B-7; (9) Shell Oil Company's Realty Operators B-8.



SW.
NE.
5500
6000
7000
8000
9000
10000
1
2
3
4
5
6
7
8
9
F_2
F_1
"P"
"P"
TOP "P" SAND
GIBSON
TERREBONNE PARISH, LA
0
4000
FEET

The northeast area has very gentle doming and closure of about 25 feet. There may be one or more faults too small to be readily detected.

Judged by the small amount of structural relief and the small throw of the faults, the salt must be at a great distance below. If this is the correct interpretation, faults "F_1" and "F_2" would be expected to increase in throw downward, becoming true major faults. A downward projection of the dip of these faults indicates that the top of the salt column is in Section 41 or farther southwest.

GRAND BAY FIELD, PLAQUEMINES PARISH

The Grand Bay dome was located in 1937 as a result of gravimeter and reflection-seismograph work carried out by the Gulf Refining Company (*Lockwood's Report*, 1940, p. 131). About a third of the producing area is located beneath the waters of Breton Sound. The discovery well was completed in July, 1938. There are six or more producing sands of Miocene age. By June, 1943, approximately 40 wells had been drilled. No salt has yet been encountered.

The subsurface structure so far revealed appears to be a part of a large gentle dome crossed by two major faults. The center of the domed area is apparently located in the vicinity of well No. 1 (in the section) on the southwest edge of the producing area. The total relief of the structure, as indicated by the combined maximum throws of the two faults, is about 550 feet.

Fault "F_1" has a northwest strike and is downthrown toward the southwest. The maximum throw is 300 feet and the dip is about 48°. Fault "F_2" also has a northwest strike and is downthrown toward the southwest. Its maximum throw is 250 feet and its dip appears to be about 60°. The structural result of these two faults is a series of steps descending southwest. There are no other indications of the presence of major faults. No minor faults were observed.

As the faults are located on the northeast flank of a domed structure, there is closure against the northeast upthrown side of both faults which results in separate oil and water levels for each sand in each block or segment. A gentle reversal of dip on the southwest edge of the producing area has provided sufficient closure to result in production from the southwest downthrown side (well No. 1 in the section). The irregularities in the pattern of contours in the central block are probably due to slight deviations in the wells.

The Grand Bay structure is similar to that of Quarantine Bay, which is located about 15 miles northwest. Although the structures are similar, the principal faults at Quarantine Bay strike northeast, or about at right angles to the faults in Grand Bay. This is believed to be good supporting evidence of the lack of regional control of any kind on the faults in individual structures in this part of the Coastal salt-dome belt. The right angle between fault strikes, however, may indicate a local relationship between these structures. Since both Grand Bay and Quarantine Bay fields represent only relatively small parts of the respective domes, it is believed that additional wells will reveal both as structures of the dome-with-graben type.

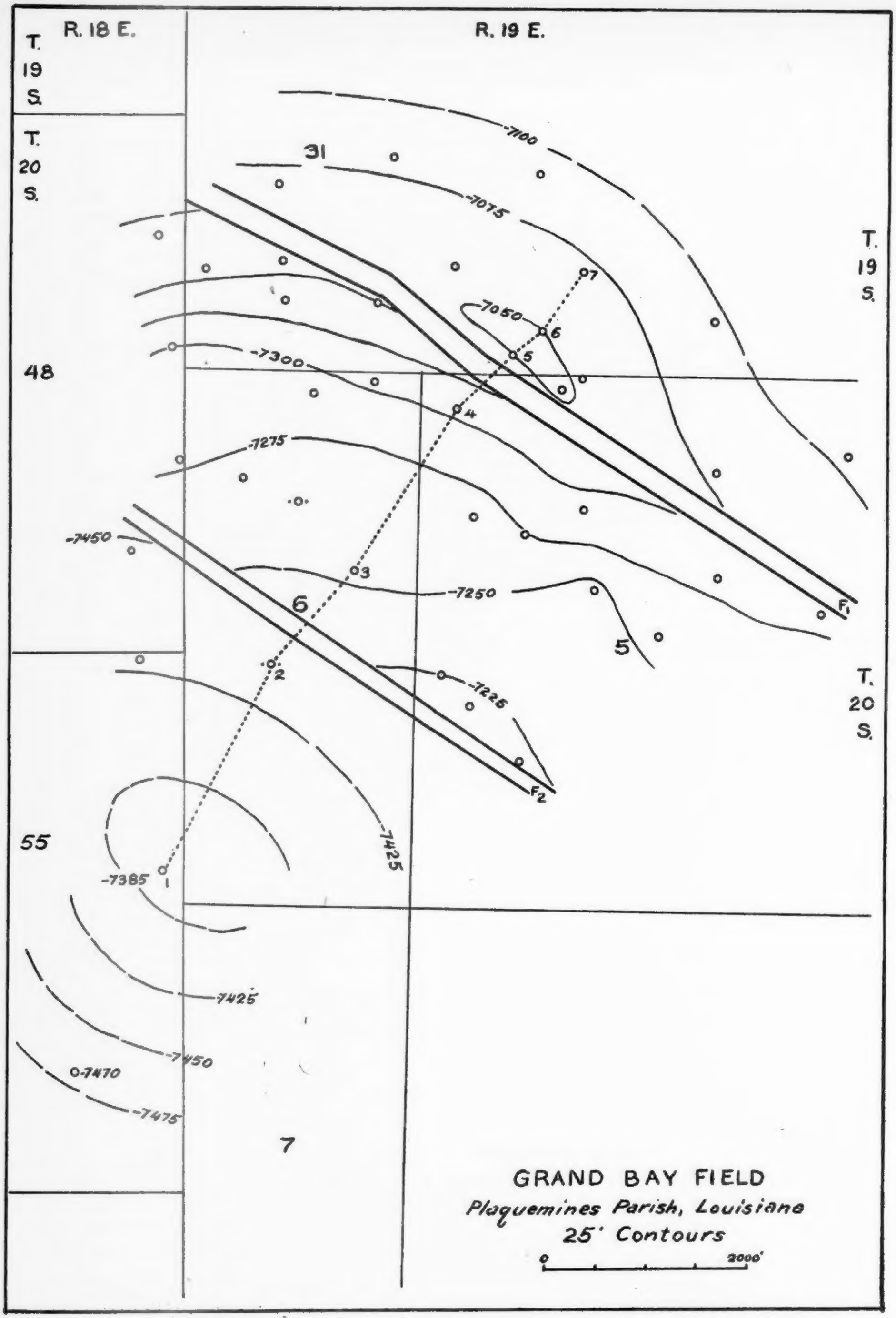


FIG. 14.—Grand Bay field, Plaquemines Parish. Wells numbered in cross section (all Gulf Oil Company): (1) Grand Prairie Levee District A-11; (2) Grand Prairie Levee District No. 1; (3) QQ No. 1; (4) QQ No. 2; (5) QQ No. 8; (6) QQ No. 7; (7) QQ No. 11.

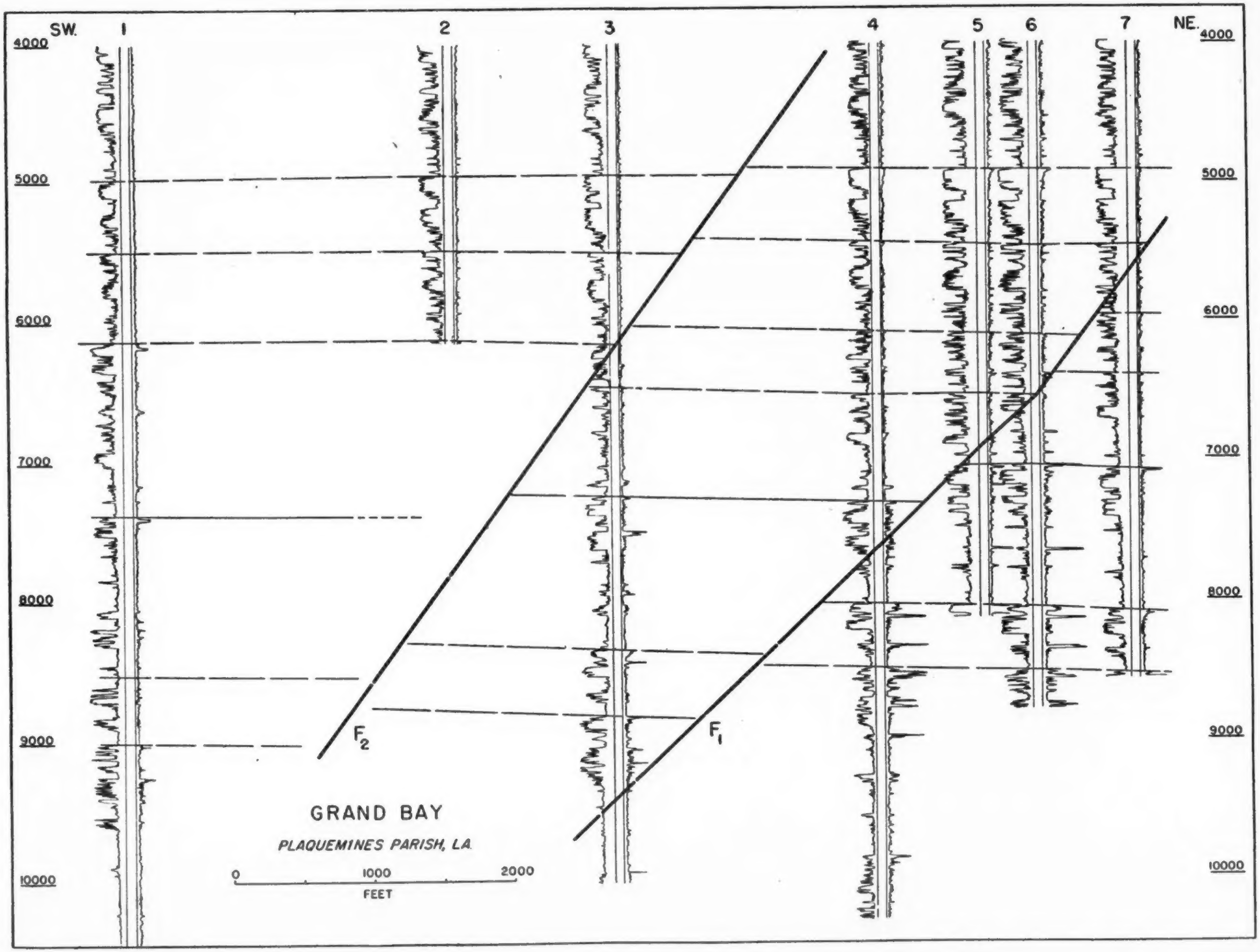


FIG. 15.—Electric-log cross section of Grand Bay field.

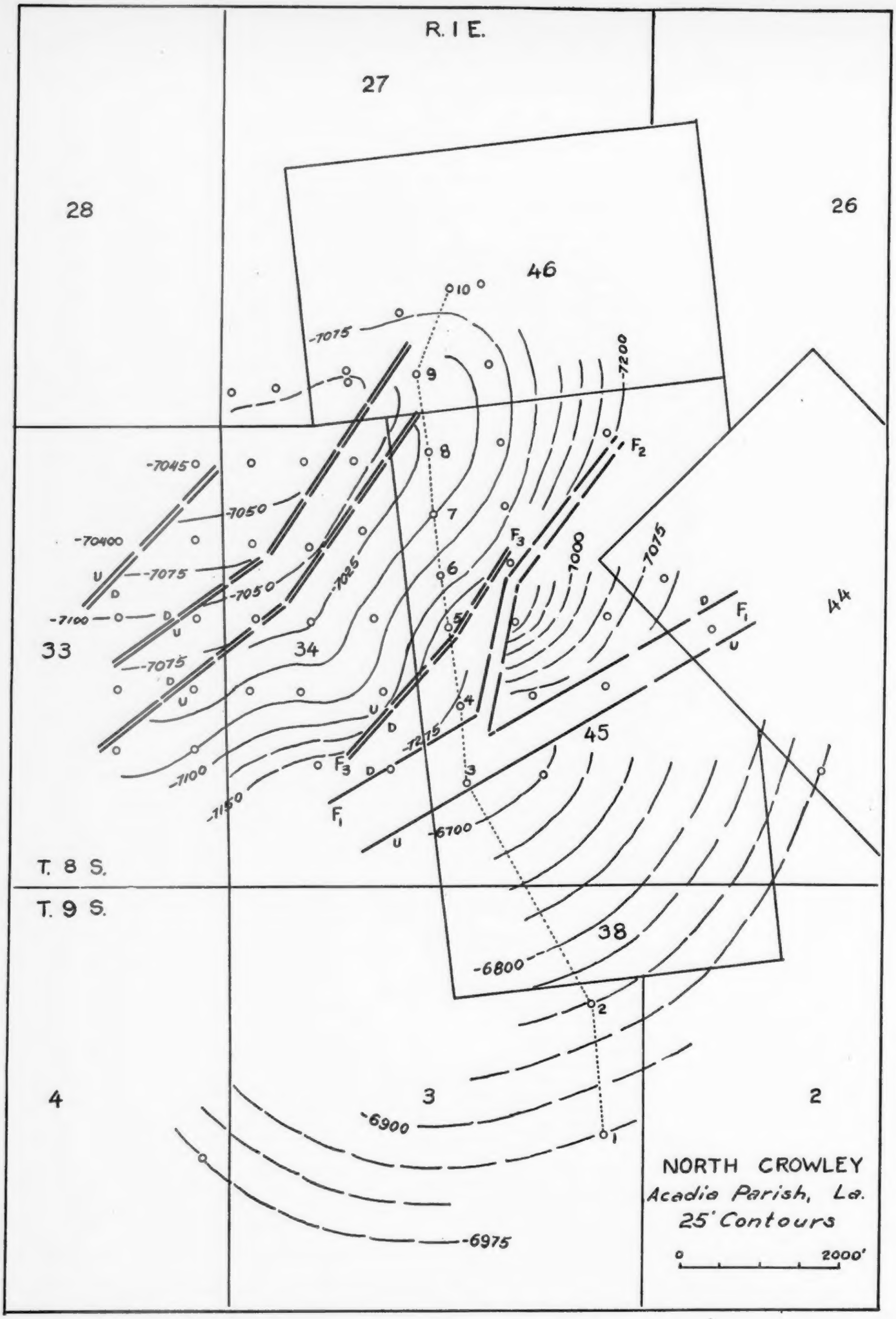


FIG. 16.—North Crowley field, Acadia Parish. Wells numbered in cross section (1–9 are Humble Oil Company): (1) Mary M. Habetz No. 1; (2) Isaac Trahan No. 1; (3) H. J. Habetz No. 2; (4) H. J. Habetz No. 1; (5) A. Olenfrost No. 1; (6) A. Olenfrost No. 5; (7) Reiner No. 1; (8) Reiner No. 2; (9) Reiner No. 4; (10) Vincent and Welsh's H. J. Fisher No. 1.

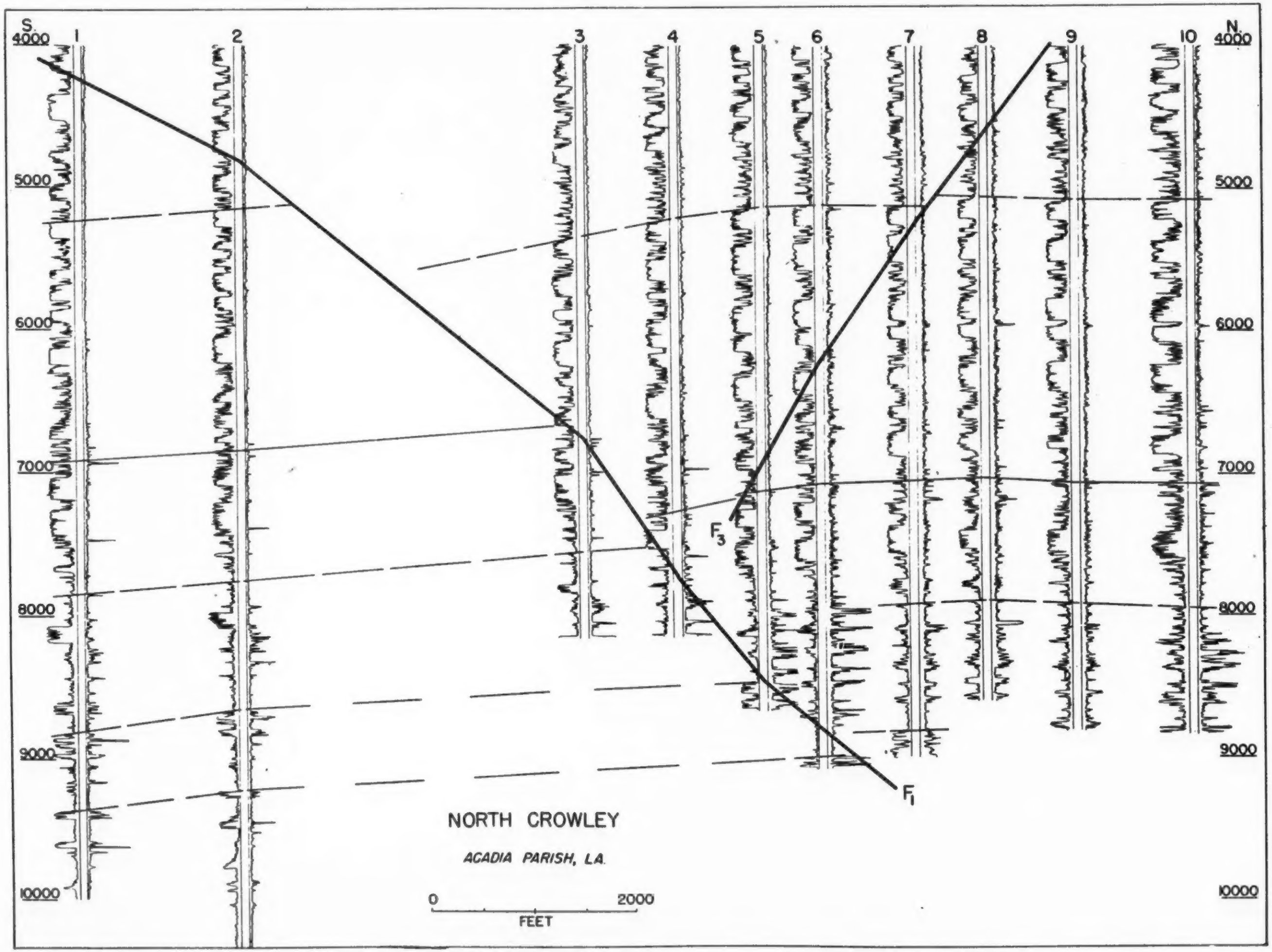


FIG. 17.—Electric-log cross section of North Crowley field.

NORTH CROWLEY FIELD, ACADIA PARISH

This structure was discovered by the Humble Oil and Refining Company in 1935 as a result of surface geology, reflection seismograph and gravity work (*Oil Weekly*, March 16, 1942, p. 99). A map showing the refraction-seismograph anomaly recognized prior to discovery of oil, is given by Rosaire (1940, p. 1410.) The discovery well was completed in September, 1937. There are a number of producing sands of Miocene age.

The subsurface structure, between the 6,500- and 7,500-foot levels, consists of segments of a broad dome crossed by two large faults and a number of minor ones. The highest part of the south flank is at least 300 feet higher than the highest part of the producing area on the north downthrown side. The largest fault, "F_1," strikes northeast and dips northwest. The maximum displacement is about 750 feet, which is believed to be approximately equivalent to the total relief of this structure. This fault divides just east of well No. 3 (in the section). One branch, "F_2," extends in a more northerly direction. "F_2" has a maximum throw of about 290 feet where it joins "F_1," and decreases to less than 200 feet at the edge of the field. The northeast extension of fault "F_1" has a throw of more than 450 feet. There is a small southwest-dipping fault, "F_3," which crosses the field with a northeasterly strike a few hundred feet west of fault "F_2." Its dip opposes that of "F_2" and its throw increases upward to a maximun of about 100 feet. This fault is considered to be complementary to the major faults, "F_1" and "F_2." At least three minor faults cross the west part of the field from northeast to southwest. The throws of these faults range from 30 to 80 feet.

The minor faults in this structure are very difficult to follow. There are several faults in the lower part of the accompanying section which can not be definitely located.

The production in this field is from both the upthrown and downthrown sides of the largest fault, "F_1." There are at least two wells (No. 5 and No. 6 in the section) which could be productive both above and below this fault. This relationship is believed to be strong evidence to support the contention that the oil accumulated in the structure prior to the faulting, which has only served to separate the original accumulation into segments with different structural levels. The wells in Sections 3, 4, and 44 are located on the southeast flank, which is on the upthrown side of the fault; they are located too far downdip to be productive.

Since this structure has no south-dipping major faults, it must be classed as a simple offset dome of a more or less intermediate type between Tepetate, which produces from the downthrown side of a major fault, and Barataria or Grand Lake, which produce from the upthrown side. The number of minor faults and the amount of throw of the major faults are believed to indicate that the top of the salt column is only a short distance below the 10,000-foot level.

LAKE LONG FIELD, LAFOURCHE PARISH

This structure was outlined by torsion balance and reflection seismograph for the Fohs Oil Company and the Pilgrim Exploration Company (*Lockwood's Re-*

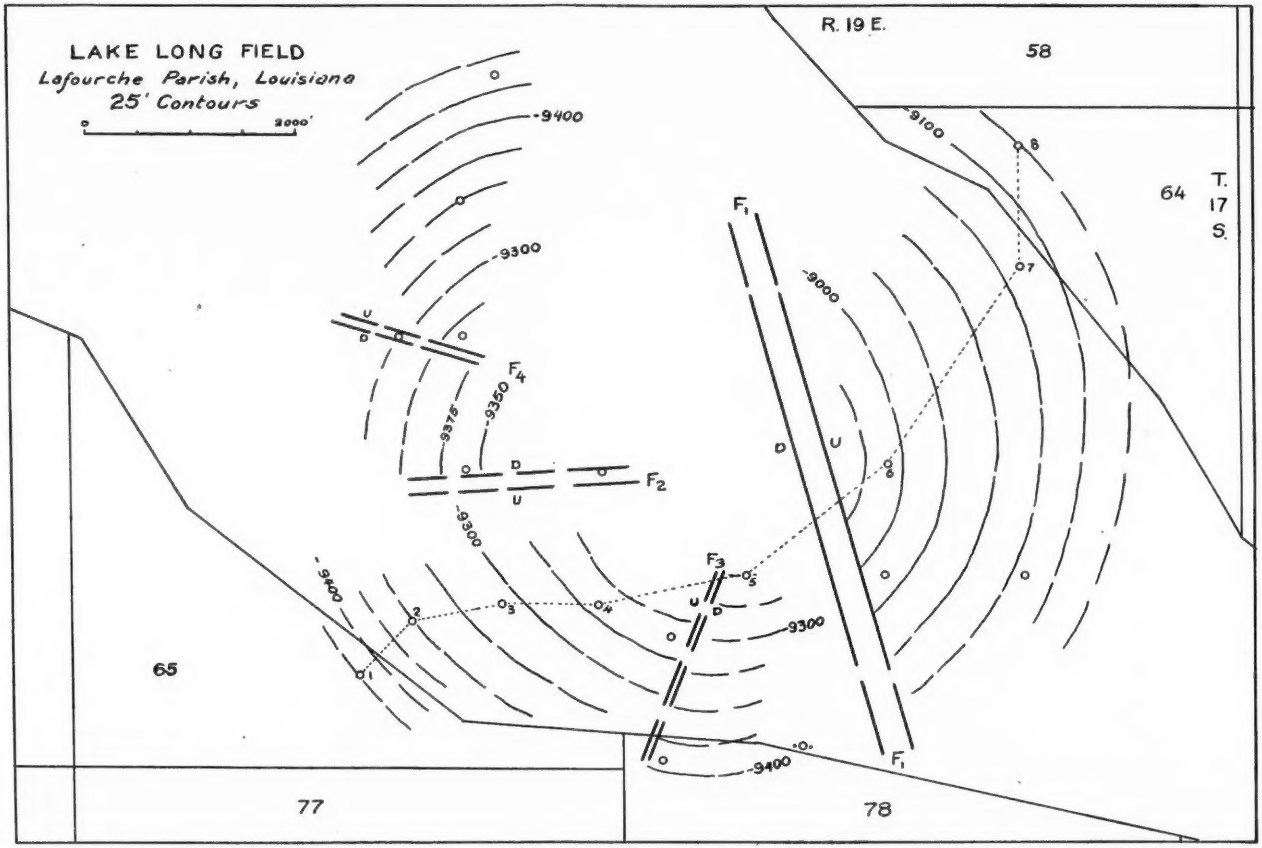


FIG. 18.—Lake Long field, LaFourche Parish. Wells numbered in cross section (all Fohs Oil Company): (1) Aucoin No. 1; (2) State Lake Long No. 15; (3) State Lake Long No. 12; (4) State Lake Long No. 5; (5) State Lake Long No. 6; (6) State Lake Long No. 11; (7) State Lake Long No. 14; (8) Allen Ranch No. 1.

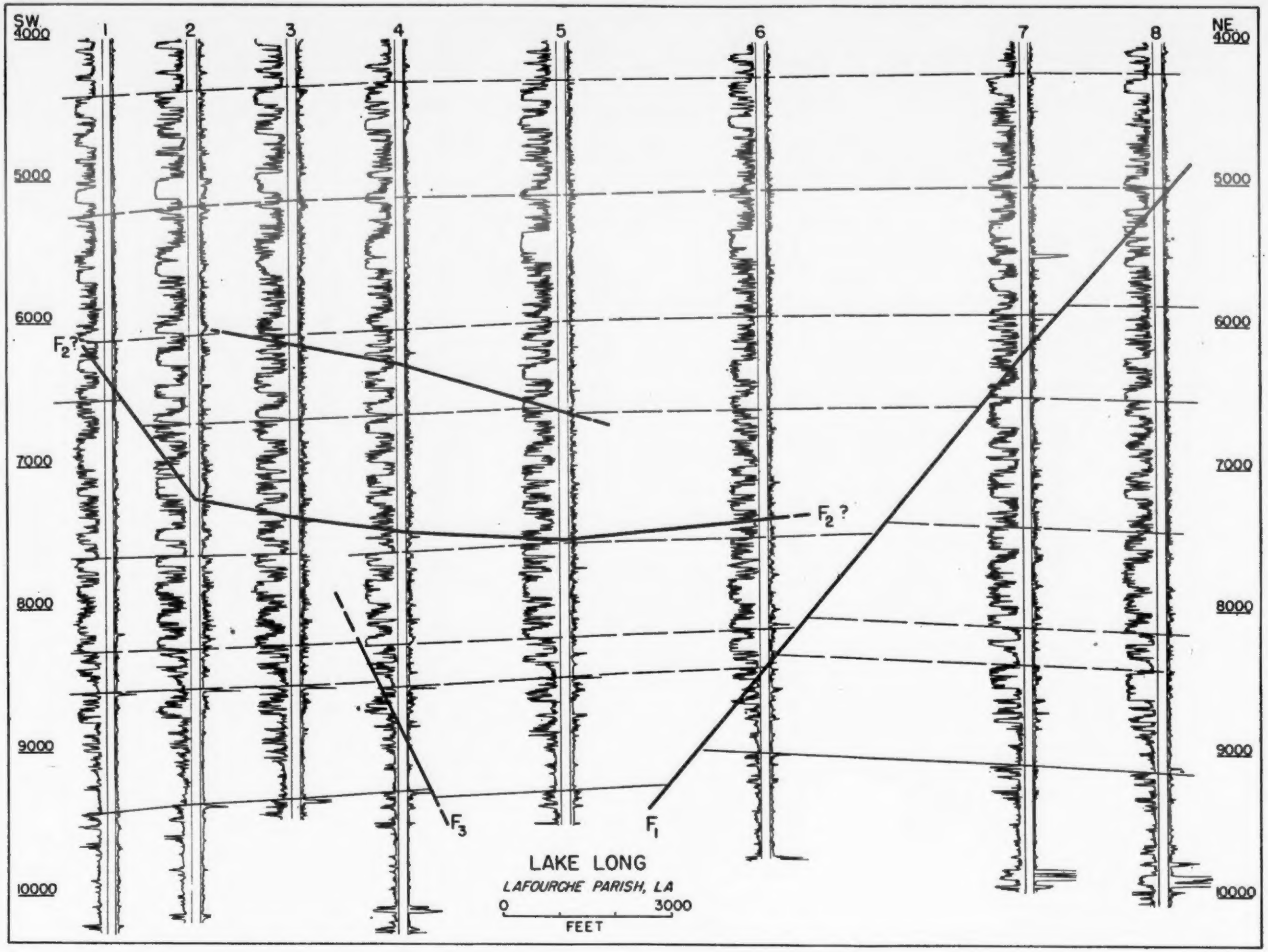


FIG. 19.—Electric-log cross section of Lake Long field.

port, 1940, p. 185). The discovery well was completed in June, 1937. There are at least five producing sands of Miocene age. No salt has been discovered to the total depth of 11,347 feet.

The subsurface structure is not too well revealed by the nineteen wells which have been drilled prior to June 1, 1943. The accompanying map represents an interpretation of the structure between the 9,000- and 10,000-foot levels. The domed area has a width of nearly $1\frac{1}{2}$ miles. The largest fault, "F_1," with a maximum throw of about 300 feet, crosses the structure with a northwest strike, and dips west. This causes the east flank to be at least 250 feet higher, structurally, than any block on the west. The east, upthrown block produces some gas.

The main producing area lies on the west, downthrown side of fault "F_1." At least three radial faults seem to be present. They have the following amounts of throw: "F_2," 150 feet, possibly more; "F_3," 50 feet; and "F_4," 90 feet. The largest of these faults, "F_2," strikes approximately parallel with the line of the section and appears between the 6,000- and 8,000-foot levels on the section. In points in the section, the throw appears to be as much as 200 feet. The production on the western flank is considerably complicated by these faults.

The structure of Lake Long is tentatively classified as a simple offset dome. It is rather exceptional in producing from both the high and low sides of the principal fault. The total structural relief, as indicated by the throw of this fault is in excess of 300 feet.

ST. GABRIEL FIELD, IBERVILLE PARISH

In 1939, following an extensive geophysical survey of the area, the Shell Oil Company drilled two non-productive wells (Nos. 7 and 8 in the section), in Sections 18 and 19. In 1940, another non-productive well was drilled in the northwest corner of Section 20. The leases were then assigned to George H. Echols who completed the discovery well in February, 1941. By June 1, 1943, 31 wells had been drilled of which 25 were productive of oil or gas. On the cross section, the tops of the "F," "J," and "K" sands are indicated. All are Miocene in age. Production is restricted to the north, upthrown side of a major fault on the northeast flank of the dome.

The subsurface structure between the 7,500- and 8,500-foot levels consists of a domed area about 3 miles in diameter with a central graben $\frac{1}{2}$ mile wide. Most of the wells have been drilled on the northeast flank outside of the graben.

The producing area consists of a small dome, slightly elongate along its northwest-southeast axis, which lies on the flank of the principal dome. Closure is due to doming except on the south edge where the producing sands are cut off abruptly by fault "F_1." The productive closure is about 60 feet on the "F" sand.

Fault "F_1" strikes northwest and is downthrown on the south. Its dip is about 58° and its maximum vertical displacement is more than 175 feet. A comparison of the fault throw in many of the wells reveals a gradual decrease upward and horizontally from the south-central edge of the producing area. This condition,

FIG. 19.—Electric-log cross section of Lake Long field.

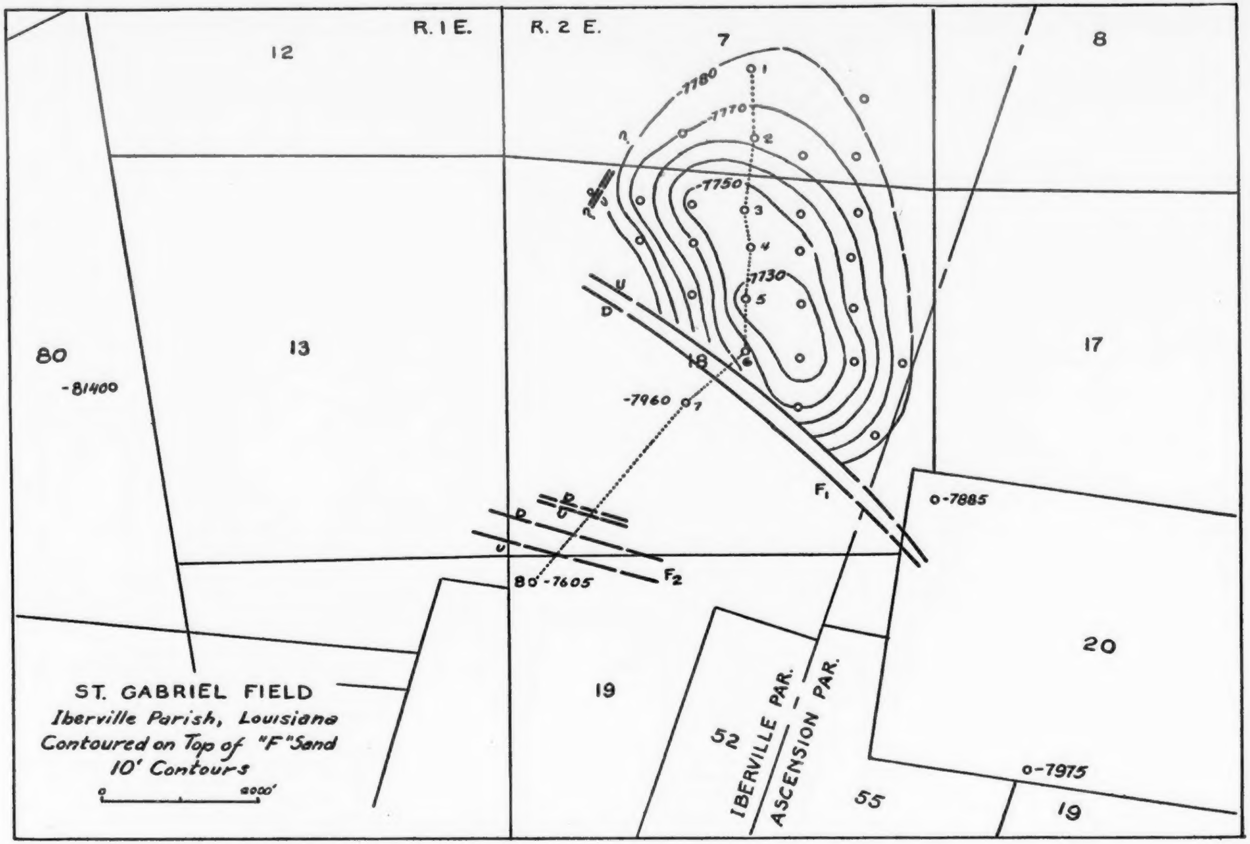
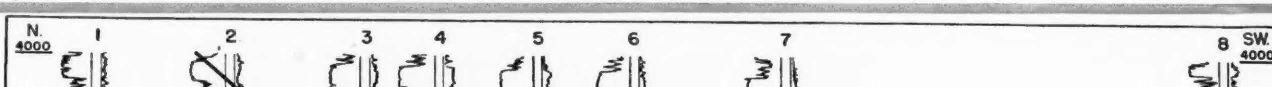


FIG. 20.—St. Gabriel field, Iberville Parish. Wells numbered in cross section: (1 and 2) George H. Echols' Natalbany A-2 and A-1; (3–6) Shell Oil Company's Shell-Gueymard Nos. 1, 3, 5, and 7; (7 and 8) Shell Oil Company's Shell-Natalbany No. 1 and No. 2.



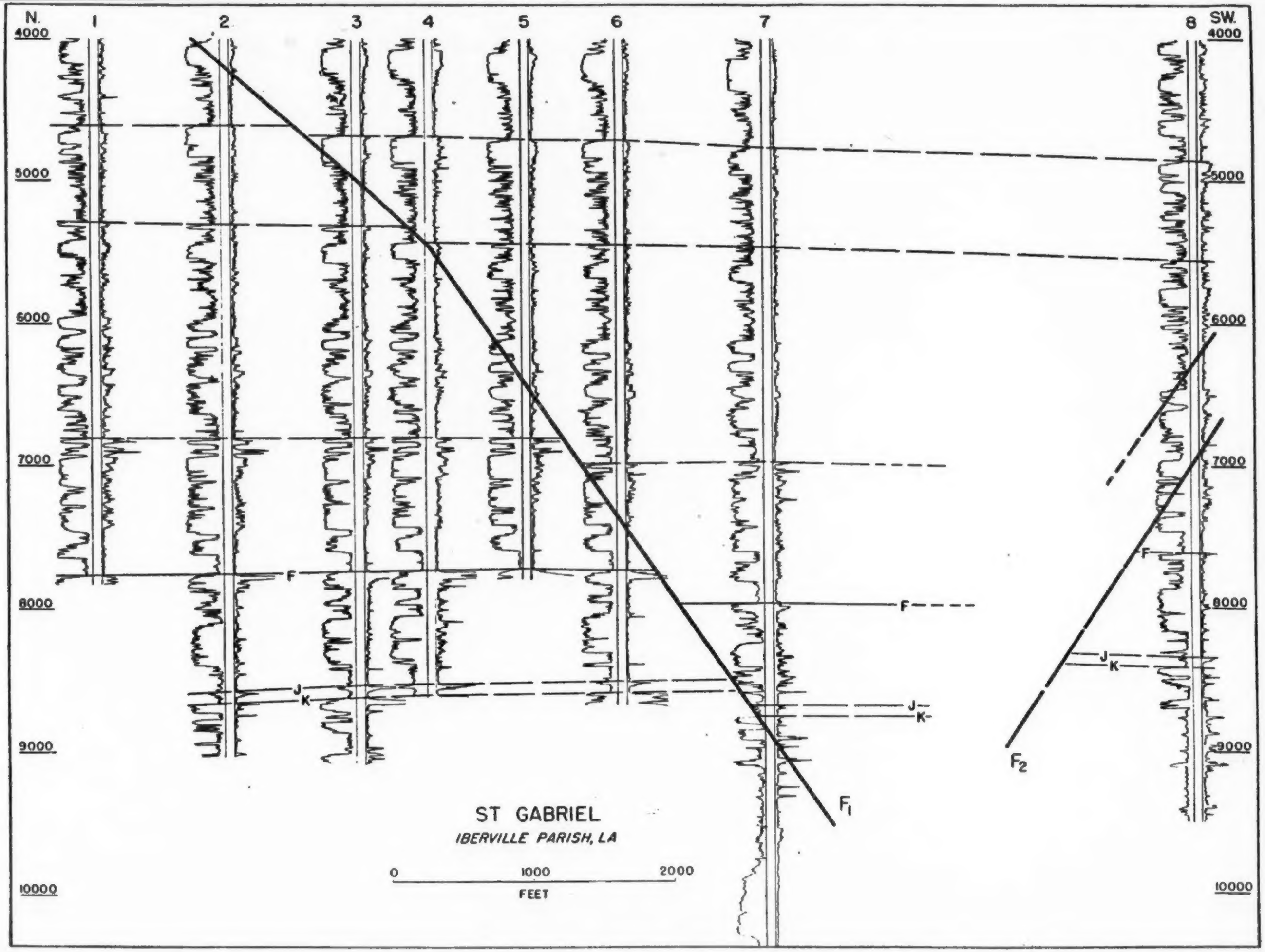


FIG. 21.—Electric-log cross section of St. Gabriel field.

which is quite evident in this field, is believed to be a common characteristic of major faults.

Major fault "F_2" has a general east-west strike and is downthrown on the north. The throw is approximately 350 feet. A short distance above, there is a smaller fault with a throw of about 100 feet. It is probably parallel in dip and strike with fault "F_2" and possibly is a branch or division of the larger fault. Fault "F_2" is believed to cut the well in Section 80 below the "F" sand and the well in the south part of Section 20 above the "F" sand. Although the south flank is 125 feet higher structurally than the north flank, it does not appear to have productive possibilities.

Between the two principal faults there is a central graben which lies 350 feet lower than the south flank and 230 feet lower than the highest part of the producing area on the north flank. A minor fault with a throw of about 40 feet is indicated on the northwest edge of the producing area.

The restriction of production to a single flank is not common in structures of the dome-with-graben type. This condition probably indicates that the dome, which was developed in the sedimentary layers prior to faulting, had its center located near the present center of closure. The original accumulation, which migrated toward the center of this original dome, has been only slightly disturbed by faulting. The higher structural position of the south flank is a result of the greater displacement of fault "F_2." Since this displacement is younger than the present accumulation of oil and gas, the south flank is probably dry. In this case the graben appears to be a short distance south of the center of doming.

The tendency of downward projections of faults to intersect just below the 10,000-foot level is taken as an indication that the head of the salt column lies a short distance below.

BATEMAN LAKE FIELD, ST. MARY PARISH

This structure was located in 1929 by the Louisiana Land and Exploration Company using the reflection seismograph (*Oil Weekly*, March 16, 1942, p. 126). The discovery well was completed by The Texas Company in December, 1937, in sands of Miocene age. To June 1, 1943, 15 wells had been drilled in the field. There are about 8 possible producing sands. No salt has been found to the total depth of 11,654 feet.

The subsurface structure between the 9,500- and 10,500-foot levels consists of a broad dome at least 3 miles wide, crossed by a central graben about 1½ miles wide. The highest point in the graben is about 400 feet lower than the highest part of the northeast flank, and 275 feet lower than the highest part of the southwest flank. The maximum amount of fault throw is about 750 feet, indicating a structural relief of at least 750 feet.

Oil is produced from the domed area within the graben and from the upthrown sides of the major faults on the northeast and southwest flanks. A broad drainage area for the original unfaulted dome is indicated by the extent of saturation in the sands outside of the graben itself.

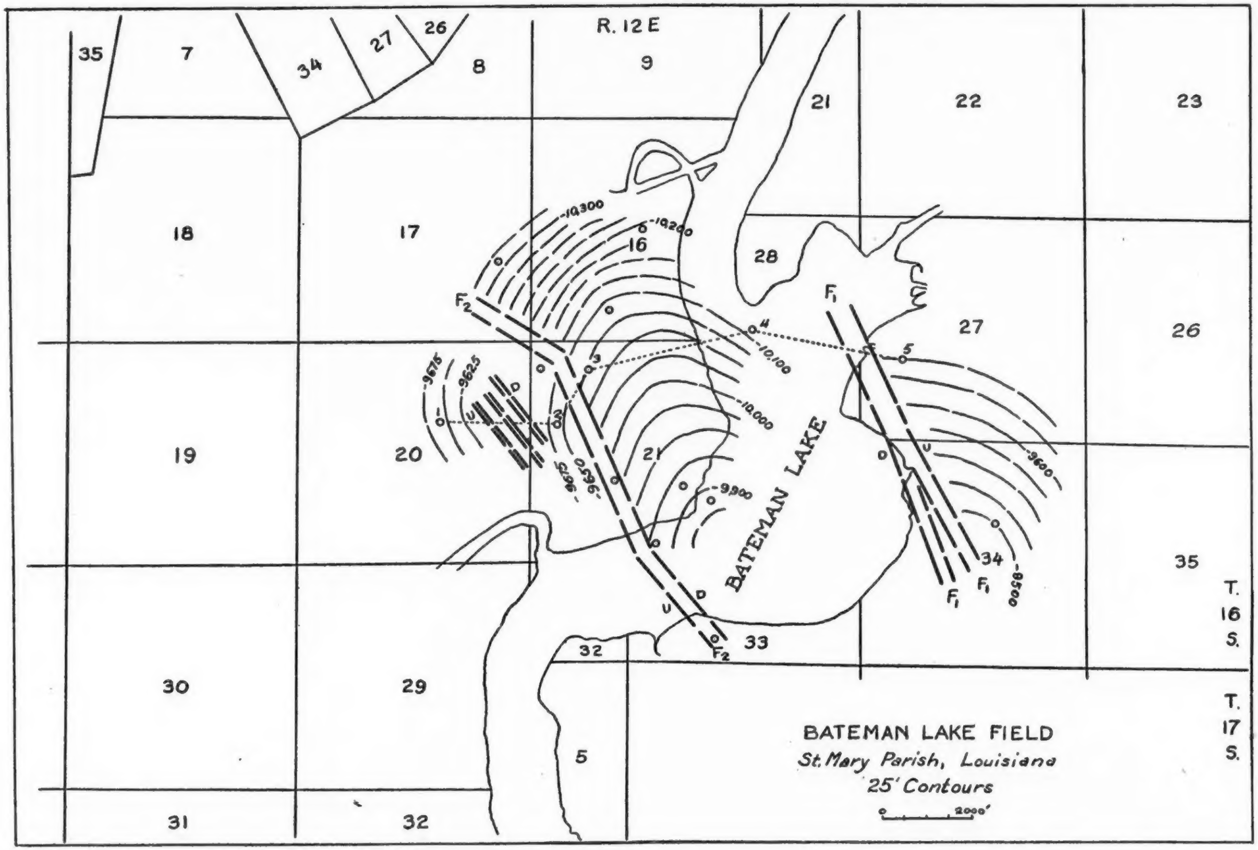


FIG. 22.—Bateman Lake field, St. Mary Parish. Wells numbered in cross section (all The Texas Company): (1) Wax Bayou No. 6; (2) Wax Bayou No. 2; (3) Wax Bayou No. 3; (4) State Bateman Lake No. 3; (5) Woodward, Kepper, and Longmire No. 1.

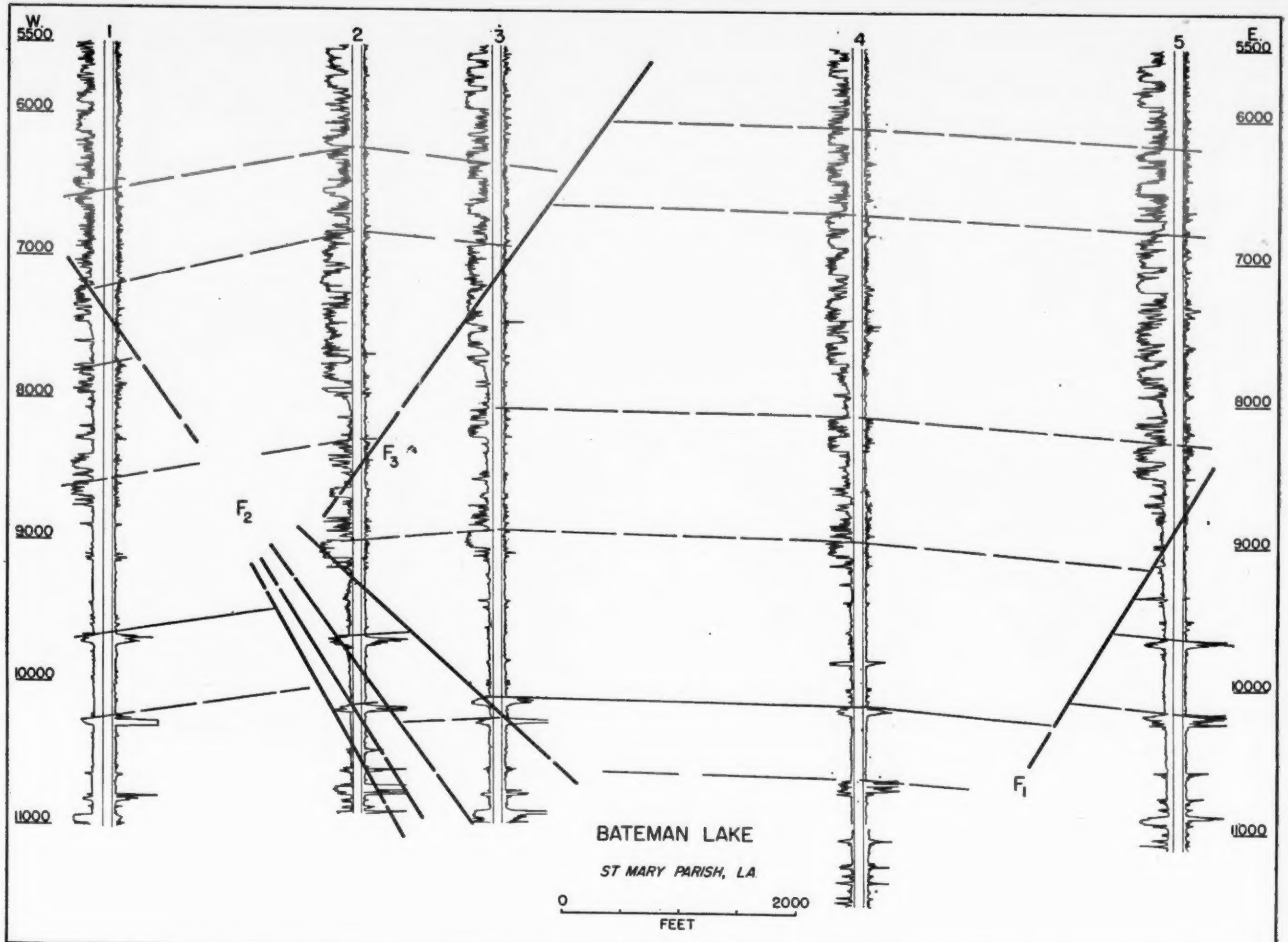


FIG. 23.—Electric-log cross section of Bateman Lake field.

There are two major faults, or rather, two major fault systems. Fault "F_1" appears in two wells. It appears to have a northwest strike, west dip, and a throw of about 600 feet. In a well in Section 34, this fault is divided into two closely spaced faults, each with a throw of about 300 feet. This major fault defines the northeast side of the graben.

Fault "F_2" defines the southwest side of the graben. It has a northwest strike south of the line of the section and is downthrown on the east. North of the line of the section it changes direction of strike abruptly to a more westerly direction. This fault has a throw of about 750 feet between the 7,000- and 8,000-foot levels. At lower levels it appears to divide into at least four units with the following amounts of throw: 475, 100, 75, and 40 feet. This branching is probably associated with the change in strike. The largest branch is labeled "F_2" on the map. Downward branching of a large fault in this manner is not uncommon. The structural result is a series of stepdown blocks within the bend of the trace of the major subdivision of the fault. The subdivisions of fault "F_2" become progressively smaller outward.

Fault "F_3" does not reach down to the contoured level. It is believed to be of the type described elsewhere in this report as complementary. Between the 6,000- and 8,000-foot levels it has a throw of about 300 feet, and between the 8,000- and 9,000-foot levels the throw decreases to 150 feet. The strike is believed to be roughly parallel with that of fault "F_2," but it is downthrown on the west, resulting in a small graben which rests against fault "F_2." Fault "F_3," if correctly interpreted, is the largest complementary fault so far observed in any of the fields studied. This condition probably results from the peculiar nature of fault "F_2" and its several subdivisions.

The Bateman lake structure may readily be classified as of the dome-with-graben type, Additional wells will probably reveal many complications not indicated in this interpretation. The large amount of throw of the faults and the intensity of complications associated with them indicates that the top of the salt plug is only a short distance below the 11,000-foot level.

LAFITTE FIELD, JEFFERSON PARISH

This structure was located in 1934 as a result of reflection-seismograph and other geophysical work carried out by The Texas Company and the Louisiana Land and Exploration Company. The discovery well was completed in May, 1935. It is reported (*Oil Weekly*, March 16, 1942, p. 114) that this was the first field in the world to produce oil from depths below 10,000 feet. There are a number of producing sands of Miocene age. No salt has yet been encountered to 12,000 feet.

The subsurface structure between the 8,000- and 9,000-foot levels consists of a dome about 5 miles in diameter crossed north and south by a central graben 2 miles wide. The apparent structural relief is about 700 feet, which is the approximate equivalent of the relief indicated by the combined throw of faults "F_1" and "F_2."

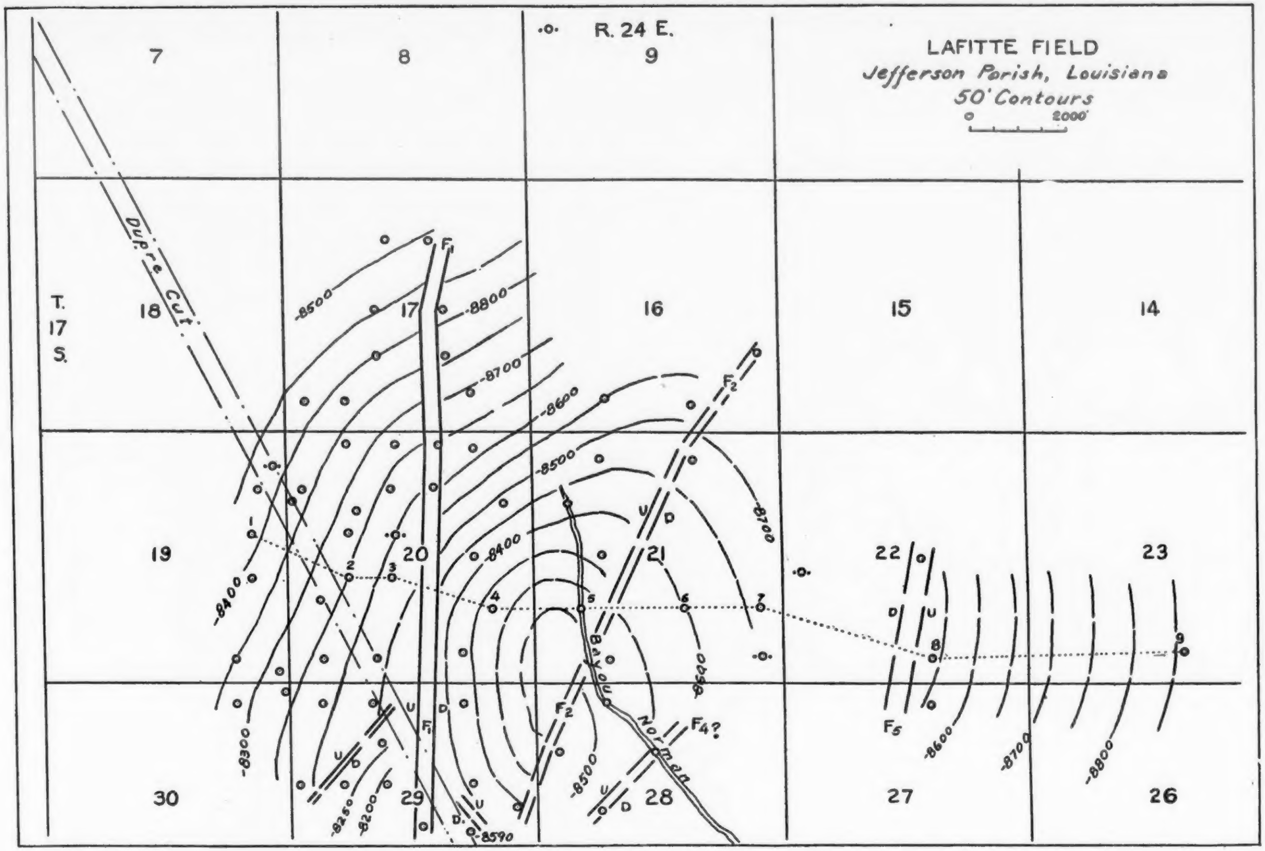
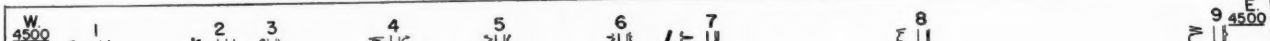


FIG. 24.—Lafitte field, Jefferson Parish. Wells numbered in cross section (all The Texas Company): (1) Madison B-1; (2) Louisiana Land and Exploration Co. No. 5; (3) Louisiana Land and Exploration Co. No. 19; (4) Louisiana Land and Exploration Co. No. 14; (5) State Bayou Norman No. 2; (6) Marrero No. 5; (7) Marrero No. 6; (8) Kerner No. 2; (9) Rojas No. 1.



ploration Co. No. 3; (3) Louisiana Land and Exploration Co. No. 19; (4) Louisiana Land and Exploration Co. No. 14; (5) State Bayou Norman No. 2; (6) Marrero No. 5; (7) Marrero No. 6; (8) Kerner No. 2; (9) Rojas No. 1.

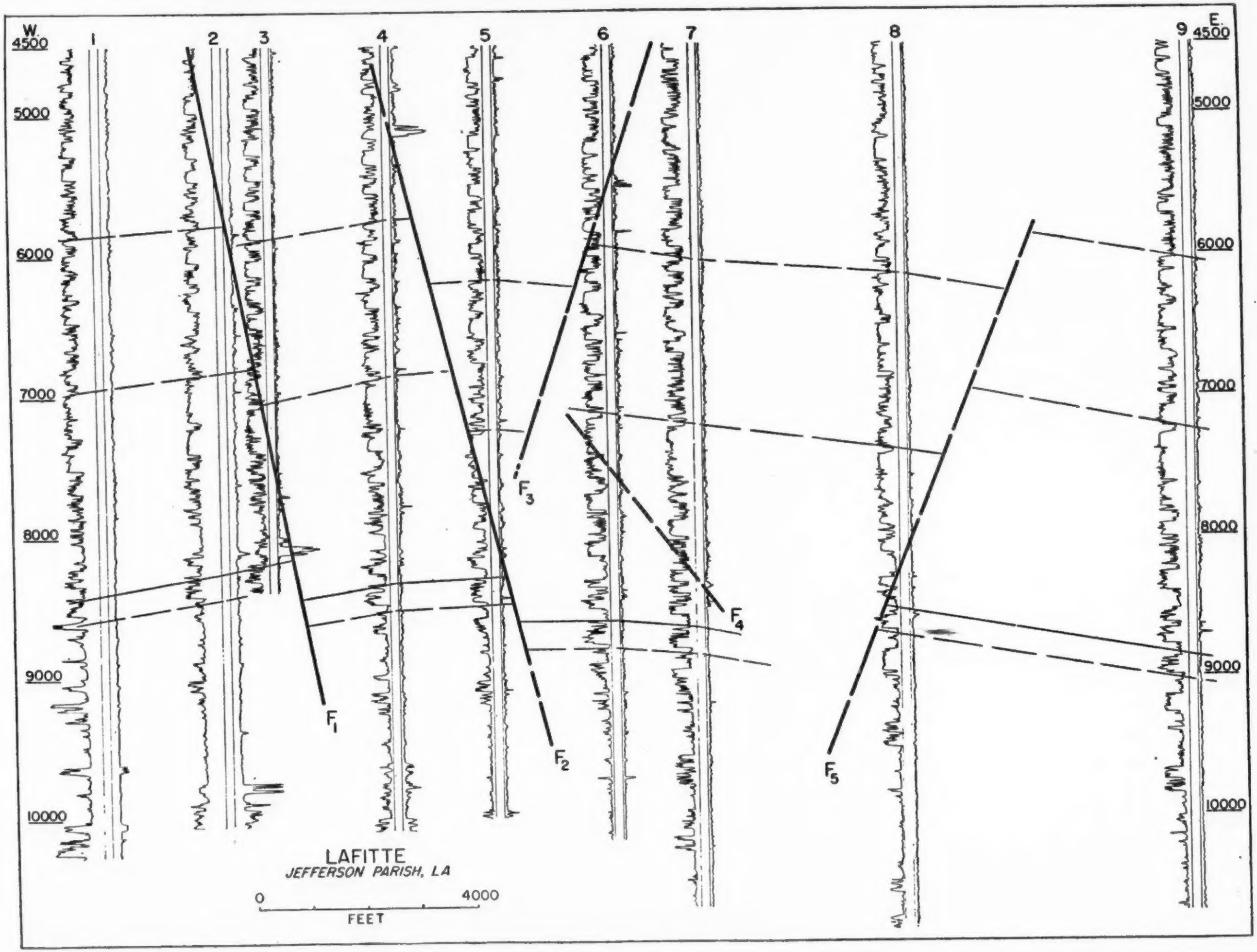


FIG. 25.—Electric-log cross section of Lafitte field.

Fault "F_1" strikes north and dips east. The maximum throw is about 400 feet. This fault forms the west edge of the graben. It provides the barrier which makes possible production from the extreme west flank of the dome.

The eastern edge of the graben is bounded by fault "F_5" which strikes north and dips west. The maximum throw is more than 500 feet. A few wells produce from the upthrown side near the fault.

The graben is divided centrally by fault "F_2" which has a northeast strike and is downthrown on the east. On the contoured horizon, this fault has a throw of about 300 feet, but at the 6,000-foot level the throw is about 450 feet. This seems to be a result of the effect of the complementary fault, "F_3", which has a throw of 300 feet at the 6,000-foot level, and a throw of 175 feet at the 7,000-foot level. Faults "F_2" and "F_3" form a graben-like wedge which occupies a position near the center of the dome. The central block is further complicated by fault "F_4" which crosses the section with a low angle of apparent dip. A fault in the center of Section 28 is probably the projection of fault "F_4." The higher parts of the graben on either side of fault "F_2" are productive.

In the west half of Section 29, a small radial fault, with a throw of about 100 feet, extends southwest from the major fault "F_1." Between faults "F_1" and "F_2" in the east part of Section 29, there is a south-dipping fault with a throw of about 200 feet.

The Lafitte structure is a typical example of the dome-with-graben. Oil is produced from both of the flanks outside the graben, and from within the graben. The south flanks have not yet been drilled. The complexity of faulting and the size of the major faults indicate the presence of salt a short distance below the 12,000-foot level.

HORSESHOE BAYOU FIELD, ST. MARY PARISH

This structure was discovered in 1929 by the Pure Oil Company using the reflection seismograph (*Oil Weekly*, March 16, 1942, p. 126). It was restudied in 1935 by The Texas Company. The discovery well was completed in August, 1937. There are a few producing sands of Miocene age. The producing sands are at levels below 9,000 feet. No salt has been encountered.

This field is exceptional in that a number of faults have been found with a small number of wells. Although the area is not well explored, there is good evidence of a dome structure crossed northwest and southeast by a complex central graben. There are at least four large and several small faults associated with this graben.

Fault "F_1", with a throw of about 500 feet, cuts well No. 1 (in the section) near the 9,000-foot level. Its direction of strike is unknown. Fault "F_2" cuts well No. 1 near the 7,500-foot level. Its throw is about 400 feet. Fault "F_2" probably dips southwest.

Fault "F_3" has a maximum throw of about 350 feet. It has a definite northwest strike and southwest dip. This fault divides into two approximately equal branch faults.

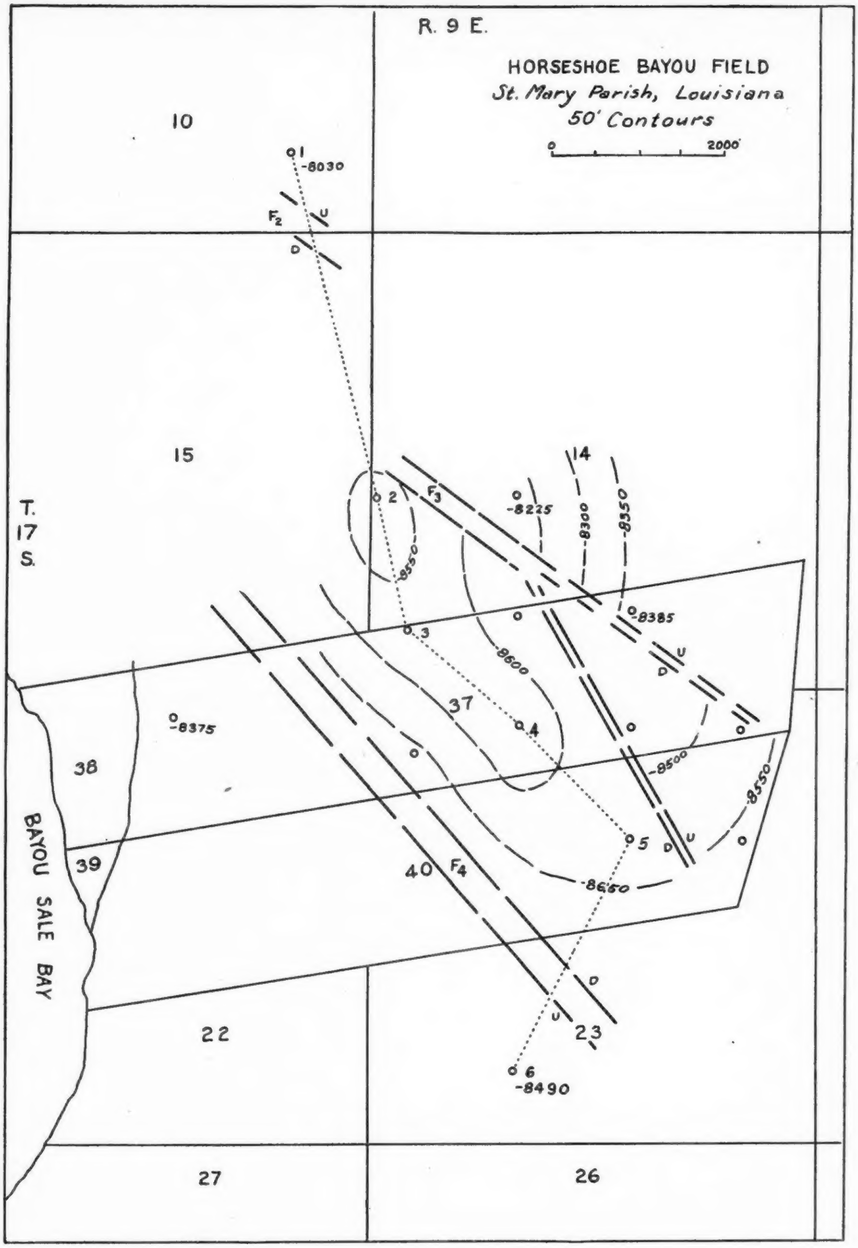


FIG. 26.—Horseshoe Bayou field, St. Mary Parish. Wells numbered in cross section (all The Texas Company): (1) St. Mary Land Co. No. 7; (2) State No. 5; (3) St. Mary Land Co. No. 4; (4) St. Mary Land Co. No. 1; (5) State No. 1; (6) State No. 4.

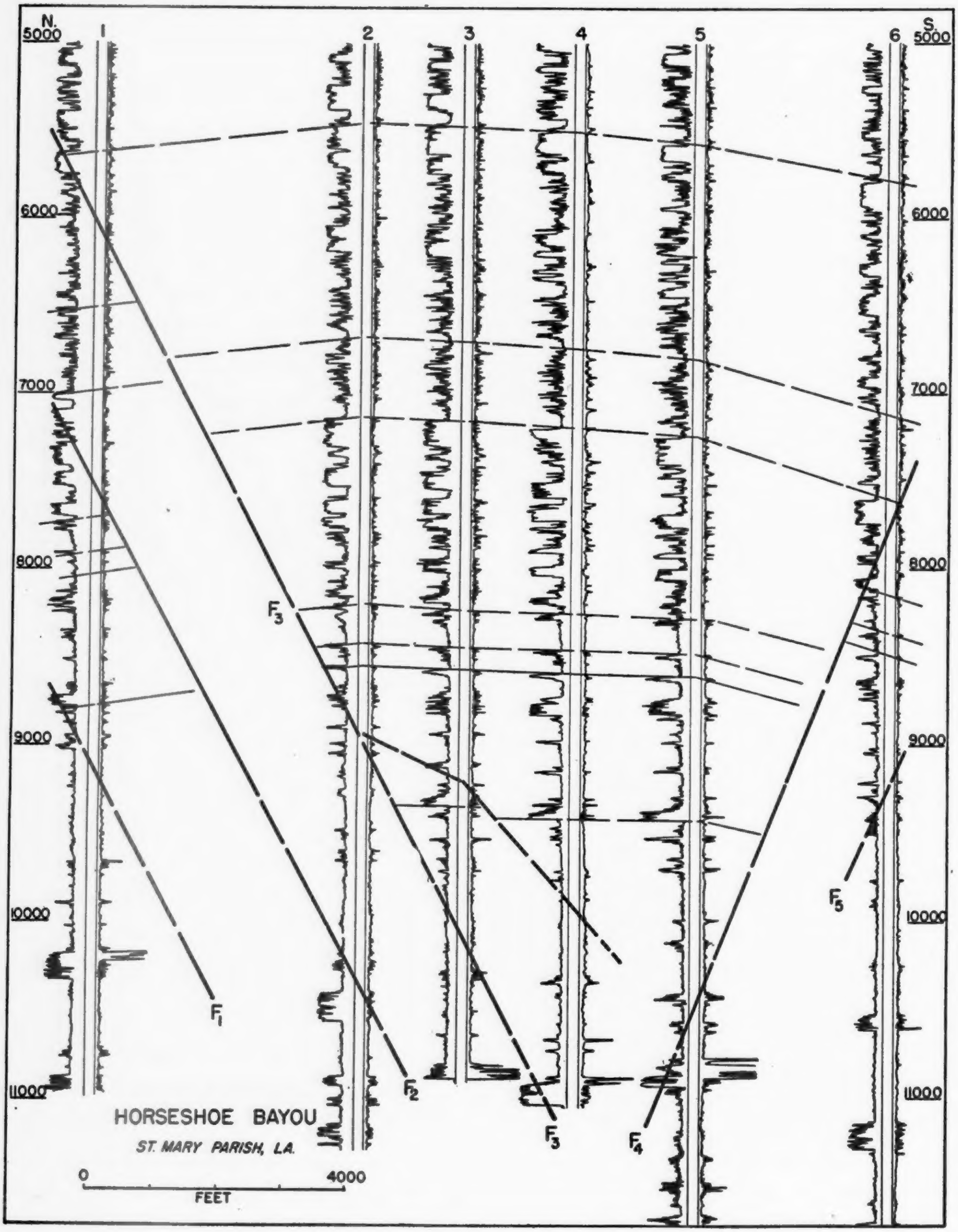


FIG. 27.—Electric-log cross section of Horseshoe Bayou field.

Fault "F_4" has a northwest strike and a northeast dip. The maximum throw is about 500 feet. It cuts well No. 6 (in the section) at the 7,750-foot level. There is a smaller fault, "F_5", which cuts this well just below the 9,000-foot level. Fault "F_5" has a throw of about 120 feet. Its strike is unknown, but is probably parallel with fault "F_4".

The graben at Horseshoe Bayou is bounded by fault "F_1" on the northeast and fault "F_5" on the southwest. The other faults divide the graben longitudinally. The central block in the graben is 600 feet lower structurally than the contoured sand in well No. 1 (in the section). The flanks of the dome lie outside of the limits of drilling. The center of the dome is probably in Section 15.

Present production is obtained from the upthrown sides of the various large faults, and seems to be dependent on finding the highest structural part of each block. The predominance of shale over sand below the 9,000-foot level increases the uncertainty of correlations and makes it impossible to determine accurately the points where the faults cut wells.

This structure, although only partly explored, appears to be a typical example of the dome-with-graben type. The large throw of the faults, together with the close approach of fault planes below the 11,000-foot level, indicates the presence of the salt plug a short distance below the bottom of the deepest wells.

ROANOKE FIELD, JEFFERSON DAVIS PARISH

Sawtelle (1936, p. 733) reports that this structure was discovered by a torsion-balance survey in 1925. On the other hand, *Lockwood's Report* (1940, p. 233) states that the structure was outlined with the torsion balance and reflection seismograph by the Vacuum Oil Company in 1928. The presence of surface indications and a torsion-balance minimum are mentioned by the *Oil Weekly* (March 16, 1942, p. 116). The discovery well was completed by the Shell Oil Company in May, 1934, following several shallow unsuccessful tests in Section 14. No salt has been discovered to the depth of 10,748 feet. The producing sands are lower Miocene in age.

The subsurface structure between the 6,000- and 7,000-foot levels appears to be the west half of a large dome cut by several large faults with a general north strike. The central part of the dome is cut by a graben about one mile wide. The east flank remains to be explored. All of the oil is produced from sands on the west-dipping flank of the dome, the closure on the east side being provided by fault "F_1" which has a total throw of about 425 feet. Fault "F_1" divides toward the north into two east-dipping radial faults: "F_2", with a throw of about 40 feet, and "F_3", with a throw of about 80 feet. The throw of fault "F_1" is about 200 feet at the north edge of the field. A small east-dipping fault, "F_4", with a throw of about 100 feet, appears on the south edge of the field. Its relation to "F_1" could not be determined.

There are a number of minor faults which become prominent at levels below 7,000 feet. The over-all effect of these faults is a flattening of the dip in the east half of Section 11 on the contoured layer. This is a somewhat false impression

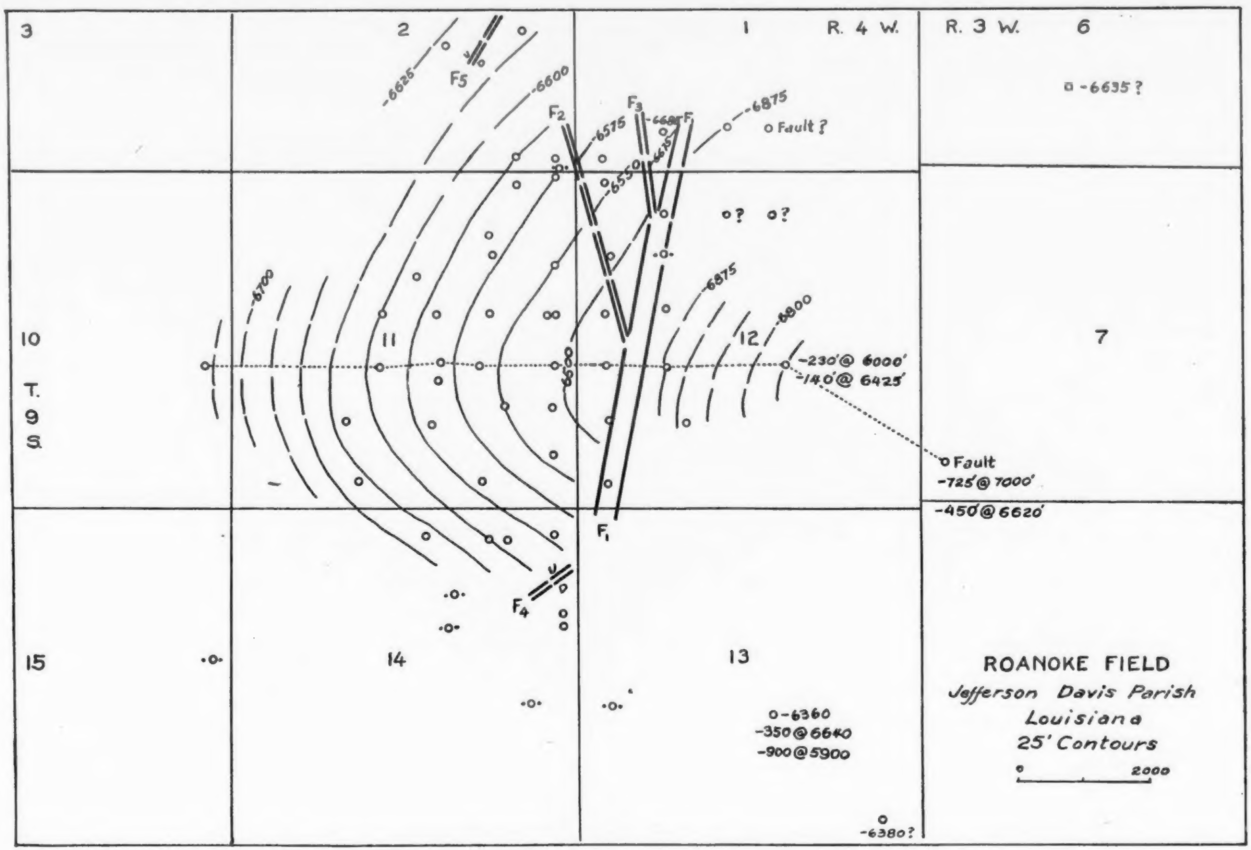


FIG. 28.—Roanoke field, Jefferson Davis Parish. Wells numbered in cross section (1–8 are Humble Oil and Refining Company): (1) T. F. Clayton No. 1; (2) DeVilbiss B-4; (3) DeVilbiss B-11; (4) DeVilbiss B-2; (5) DeVilbiss B-1; (6) C. N. Taylor No. 1; (7) C. N. Taylor No. 2; (8) R. C. Jarnigan No. 1; (9) Union Sulphur Company, Inc., F. C. Perl No. 1.

FIG. 28.—Roanoke field, Jefferson Davis Parish. Wells numbered in cross section (1–8 are Humble Oil and Refining Company): (1) I. F. Clayton No. 1; (2) DeVilbiss B-4; (3) DeVilbiss B-11; (4) DeVilbiss B-2; (5) DeVilbiss B-1; (6) C. N. Taylor No. 1; (7) C. N. Taylor No. 2; (8) R. C. Jarnigan No. 1; (9) Union Sulphur Company, Inc., F. C. Perl No. 1.

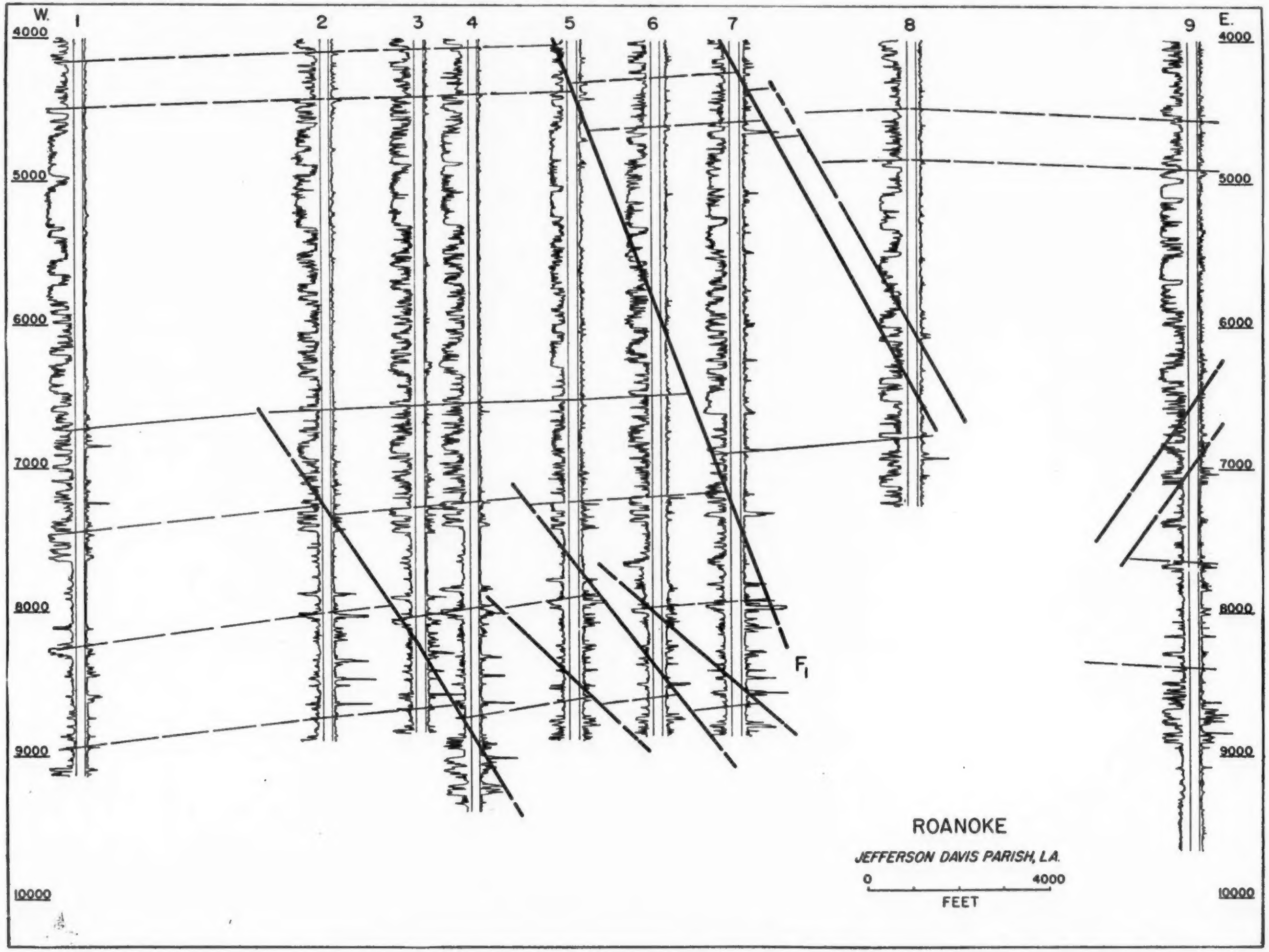


FIG. 29.—Electric-log cross section of Roanoke field.

since this part of the structure is cut by a series of very small faults which can not be shown on the map. Several of these appear in the section. It was found to be almost impossible to trace these faults for any distance.

On the extreme northwest flank a small east-dipping fault, with a throw of about 65 feet, has provided sufficient closure to result in an extension of production.

Practically no satisfactory details of structure could be obtained in the area east of the center of Section 12. Well No. 8 (in the section) contains a pair of east-dipping faults with a combined throw of about 370 feet. Well No. 9 (in the section) has at least two large faults. One, at a depth of 6,670 feet, has a throw of 450 feet and one at 7,000 feet has a throw of 725 feet. Both are believed to dip west, completing the central graben. These two faults bring the east flank of the dome to a structural position a few hundred feet higher than the west flank. The combined displacement of the fault in well No. 9 would suggest that the total structural relief of the dome is about 1,200 feet or more.

A well about 1,000 feet southeast of the center of Section 13 contains a fault with a throw of 900 feet at the depth of 5,900 feet and one with a throw of 350 feet at the depth of 6,640 feet. The relation of these faults to those previously mentioned is not known.

The Roanoke structure may be classed as the dome-with-graben type. It should be pointed out, however, that some if its major faults have exceptionally large amounts of throw, indicating a large amount of salt movement during or after late Miocene time. The top of the salt is probably at a depth close to 11,000 feet.

GILLIS-ENGLISH BAYOU FIELD, CALCASIEU PARISH

According to Leyendecker (1935, p. 62) the Gillis field, on the north half of the structure, was discovered by the Union Sulphur Company, using reflection seismograph after gas seepages had called attention to the area. Torsion-balance surveys for the Gulf Refining Company and the Shell Petroleum Corporation were carried out several years later. After two unsuccessful attempts, the discovery well was completed in a sand of lower Miocene age in 1934. A reflection-seisomograph map of the area is given by Eby and Clark (1935, p. 376).

The English Bayou field is about one mile south of the Gillis field on the south half of the dome. Torsion-balance surveys were completed in 1933. Detailed reflection-seismograph work was done for the Fohs Oil Company. Several faults were located. Leyendecker (1935, p. 62) states that this operator's torsion-balance picture is similar to that of the Iowa dome about 8 miles east. The discovery well was completed in February, 1935.

According to Leyendecker (1935, p. 63) the Gillis-English Bayou dome lies on a large salt ridge, which includes Iowa, Welsh, Roanoke, and possibly Lockport, and this ridge is expressed as a minimum ridge with the oil fields located at the apexes.

The subsurface structure of the Gillis-English Bayou area between the 6,000- and 7,000-foot levels may be described as a circular dome at least $2\frac{1}{2}$ miles in

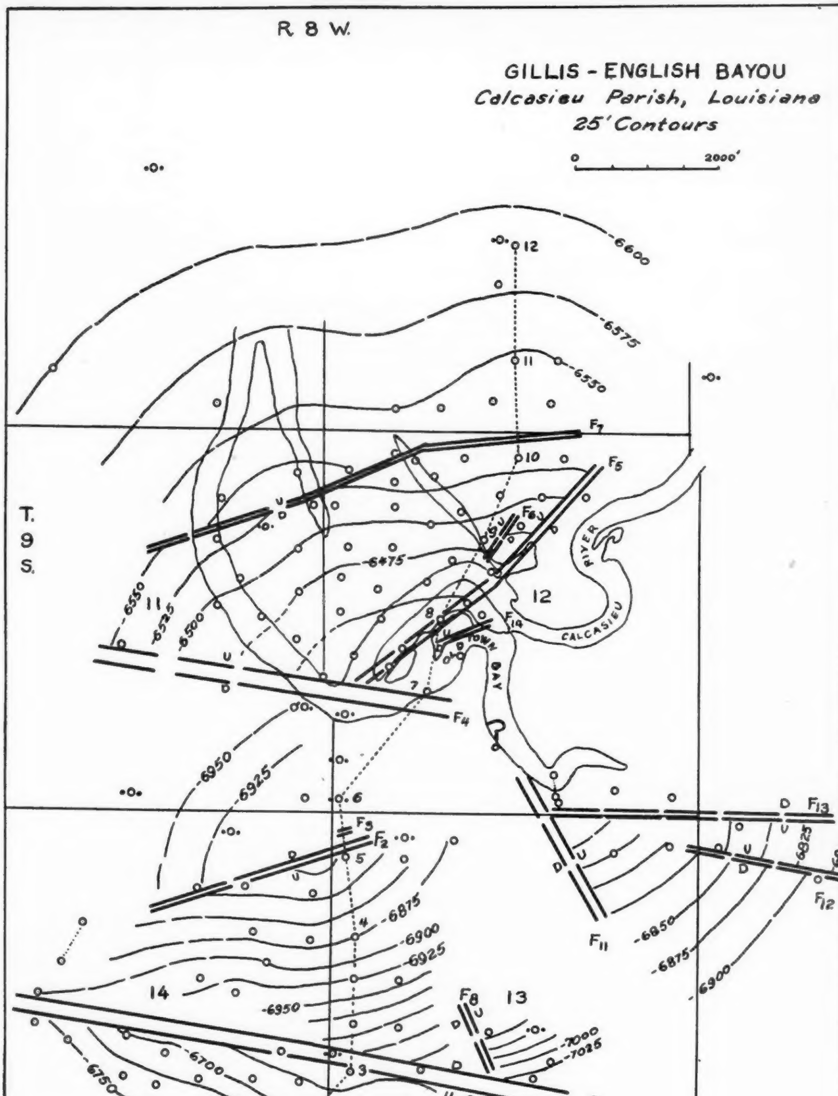


FIG. 30.—Gillis-English Bayou field, Calcasieu Parish. Wells numbered in cross section (1–3 are Fohs Oil Company): (1) M. P. Erwin 1-B; (2) Wasey No. 1; (3) Castle No. 5. (4–7, Union Sulphur Company): (4) Castle No. 8; (5) Castle No. 9; (6) Cole No. 1; (7) State No. 6; (8) The Texas Company's Nickerson No. 3. (9–12, Union Sulphur Company): (9) Powell No. 5; (10) Powell No. 9; (11) Barbe No. 13; (12) Barbe No. 12.

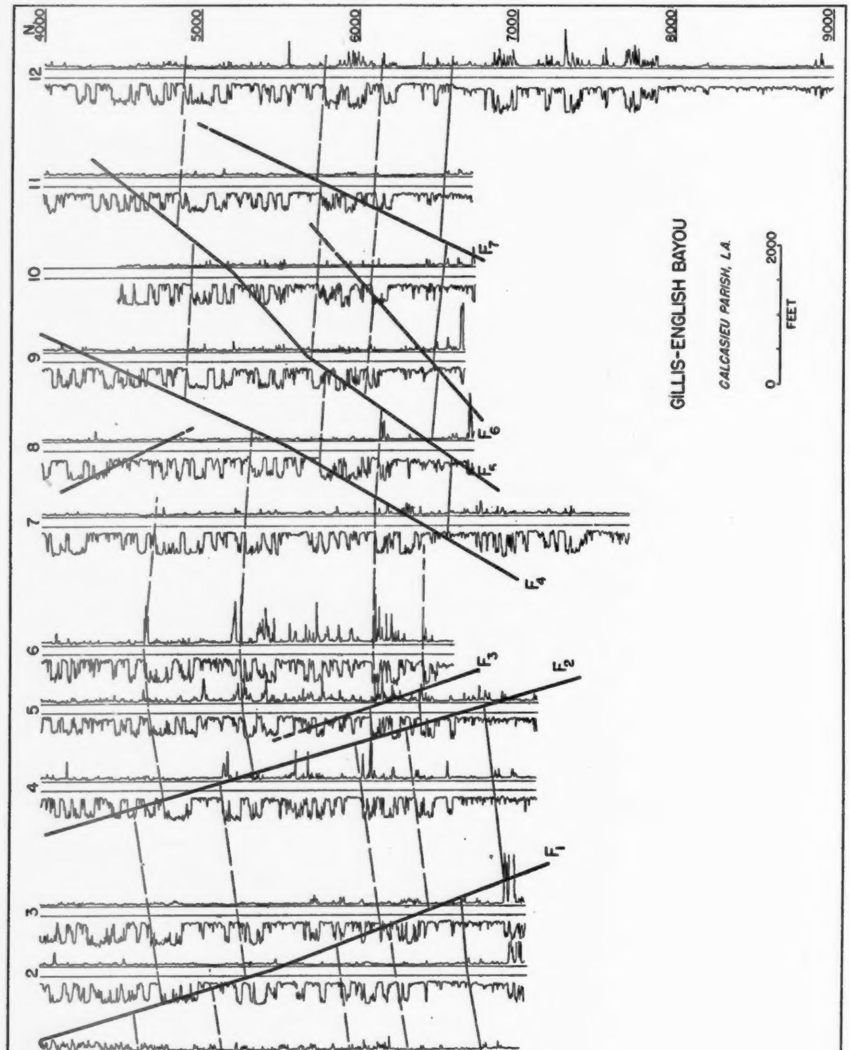


FIG. 31.—Electric-log cross section of Gillis-English Bayou field.

diameter, crossed east and west by a central graben one mile wide. Besides the two most prominent faults which form the graben, there are several faults of the radial type. The maximum effective closure is not more than 250 feet. The blocks on the south flank show steeper dips than those on the north.

The south flank of the dome rises steeply toward fault "F_1", which strikes roughly east and has a maximum throw of about 275 feet. This flank is productive on the south, upthrown side of this fault. The east end of this block is broken by a small north-striking radial fault, "F_9", and a small east-striking minor fault, "F_{10}", which appears to have parallel dip and strike with the major fault "F_1".

The central graben, located between the north-dipping major fault, "F_1", and the south-dipping major fault, "F_4", is cut by a pair of longitudinal faults, "F_2" and "F_3," which dip north. Their combined displacement is about 125 feet. Although they may be described as minor, they provide an effective oil seal which has resulted in an area which produces from the beds within the graben which dip south toward fault "F_1". The location of this producing area within the graben is proof of the accumulation of the oil within the dome prior to faulting. Oil sands which were co-extensive have now been dislocated and sealed off by fault "F_1". Leyendecker (1935, p. 63) mentions that several sands in the vicinity of fault "F_1" are hardened to solid rock but are porous and oil-bearing a short distance away. The failure of two wells to produce from the upthrown side of the fault is attributed to the cementing of sands near the fault.

The east end of the graben is cut by four radial faults, "F_8", "F_{11}", "F_{12}", and "F_{13}". In the extreme east end, the upthrown sides of these faults produce traps which support a few producing wells.

The north flank of the dome is separated from the graben by a large major fault which strikes east and is downthrown on the south. There is a structural relief of about 500 feet between the highest part of the flank and the lowest block of the graben. Fault "F_4" has a maximum throw of about 500 feet which indicates that the total relief of the structure is also 500 feet or more. The throw of fault "F_4" is about 350 feet between the 4,000- and 5,000-foot levels. The north flank is divided by a large radial fault, "F_5", with a maximum throw of about 120 feet, and two smaller radial faults, "F_6" and "F_{14}". Fault "F_5" strikes northeast and probably abruptly terminates on intersecting major fault "F_4". It serves as an effective seal to the sands on its northwest side and, together with fault "F_4", creates the broadest producing block within the field. This northwest, producing flank is crossed east and west by a minor fault, "F_7", which has a throw of about 50 feet. This fault tends to retard the free migration of the oil updip to the highest part of the flank and thus extends the productive area a short distance north.

This structure is a typical example of the dome-with-graben type. It demonstrates the large number and variety of faults which complicate structures of this type. It is believed that a few other patches of production remain to be discovered. The oil originally in the unfaulted dome is still in the general area of

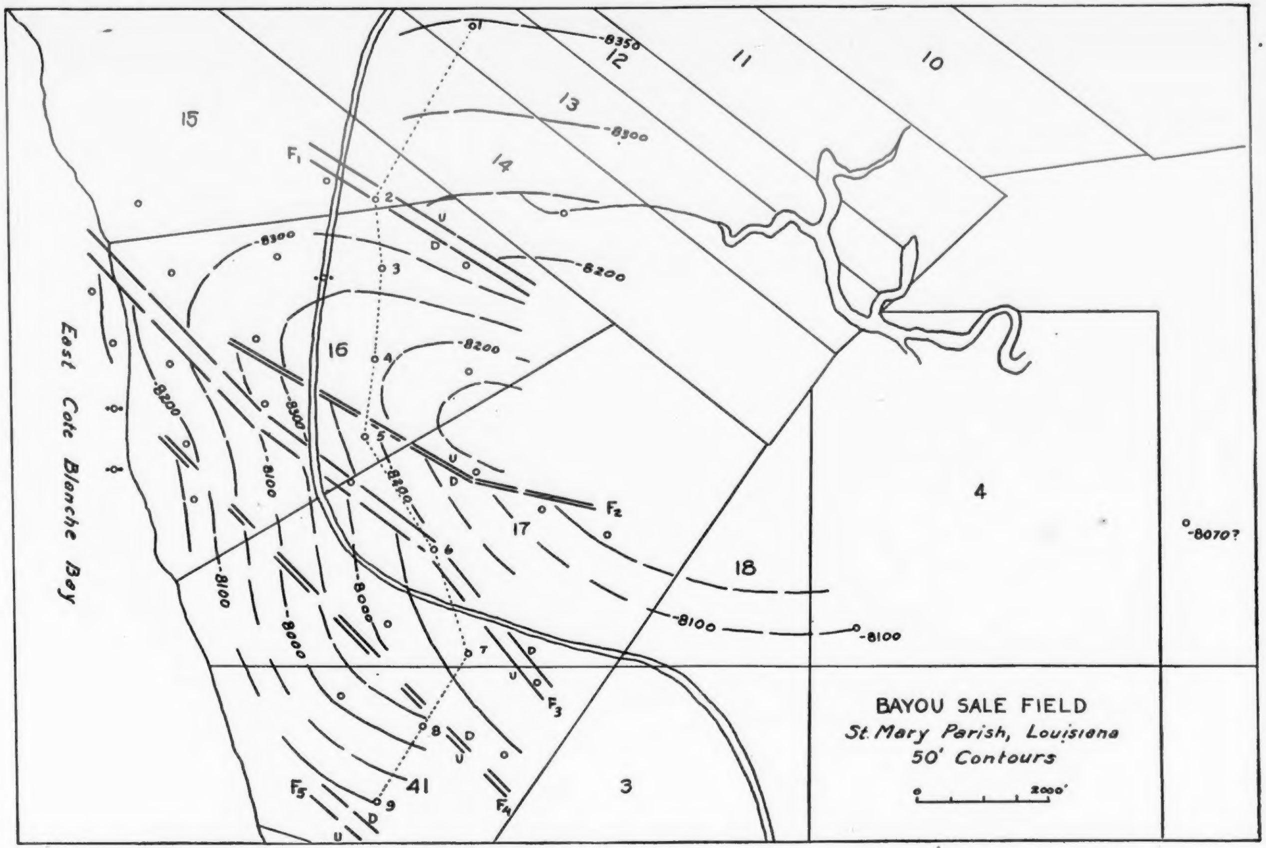


FIG. 32.—Bayou Sale field, St. Mary Parish. Wells numbered in cross section (1–6 are Humble Oil and Refining Company): (1) H. H. Gates No. 1; (2) E. F. Marin No. 2; (3) E. F. Marin *et ux.* No. 1; (4) E. F. Marin No. 3; (5) E. F. Marin No. 4; (6) Dave Luke No. 5. (7–9, Atlantic Refining Company): (7) St. Mary Parish Land Co. No. 1; (8) St. Mary Parish Land Co. No. 2; (9) St. Mary Land Co. No. 5.

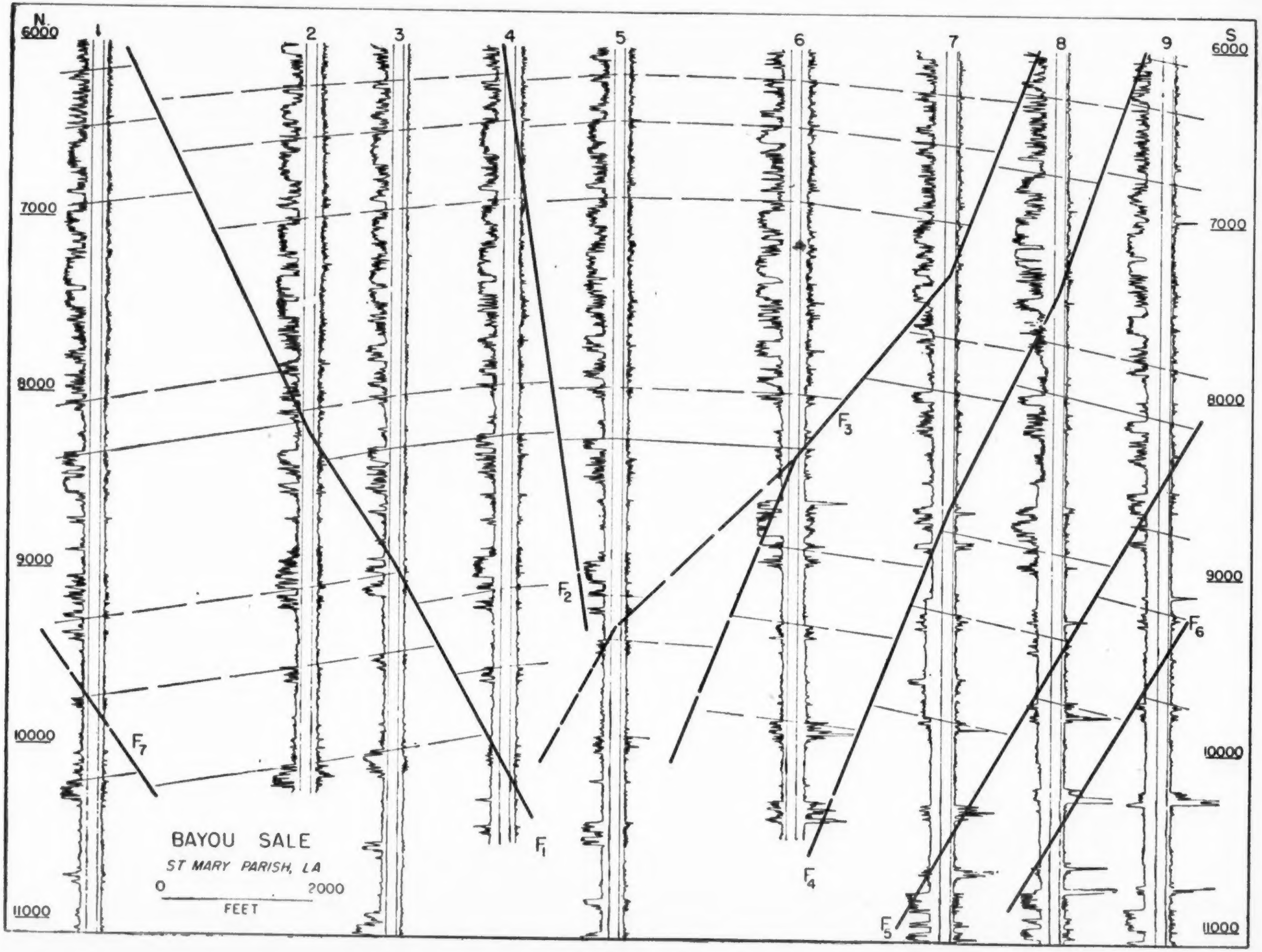


FIG. 33.—Electric-log cross section of Bayou Sale field.

the center of the dome. Faulting has caused it to be separated into small patches in the highest parts of the individual fault blocks. The large number of faults present, their fairly large size, and the relief of the structure are believed to indicate that the top of the salt lies only a short distance below.

BAYOU SALE FIELD, ST. MARY PARISH

This structure was discovered in 1937 by the Humble Oil and Refining Company, using the reflection seismograph (*Oil Weekly*, March 16, 1942, p. 126). The discovery well was completed in April, 1941. The producing sands are Miocene in age. No salt has been found to the maximum depth of about 12,500 feet.

This structure is another example of a dome with a complex central graben. Most of the wells appear to penetrate the west half of the graben. The graben extends northwest and southeast. It is about $2\frac{1}{2}$ miles wide near the 8,000-foot level.

The most prominent fault on the northeast side of the graben is fault "F_1" which has a southwest dip and a maximum throw of about 250 feet.

The graben is bounded on the north by fault "F_7" which cuts the lower part of well No. 1 (in the section). Its direction of strike is not known. Its throw is about 100 feet.

A minor fault, "F_2", with a throw of about 75 feet, causes a slight central dislocation in the graben. Its dip in the section is very steep. It is downthrown toward the south.

All of the other faults dip northeast. The following throws were observed: "F_3", 400 feet; "F_4", 100 feet; "F_5", 300 feet; and "F_6", 100 feet or more. Fault "F_6" bounds the southernmost edge of the graben. Fault "F_3" divides into two parts as it approaches fault "F_1". The relationship of the fault blocks is not clear in the vicinity of this junction of faults.

Production is almost entirely from within the graben and is controlled by the complex system of faults. The upthrown sides of all of the larger faults have narrow bands of possibly producing sands. A few of the southernmost wells may be producing from the south flank on the upthrown side of fault "F_6" which probably forms the south boundary of the graben.

A comparison of this field with Horseshoe Bayou shows some interesting relationships. The limits of production are less than 2 miles apart. The principal faults in both structures have northwest strikes. Both structures are typical examples of the dome-with-graben type. The relation of two such structures must result in a horst between the grabens.

The complexity of faulting indicates the presence of the top of the salt plug a short distance below the 12,000-foot level.

LAKE MONGOULOIS FIELD, ST. MARTIN PARISH

As the deep-seated domes studied for this report do not reach salt, it was thought advisable to examine the structure of a dome in which the top of the salt was known, but in which it appeared at considerable depth, so that the approach of the faults to the salt could be observed. For this purpose the Lake Mongoulois

deep-seated salt dome (3a), with a minimum known salt depth of 7,526 feet, was selected. There are only 10 wells on this structure, but since 8 of these lie in a nearly straight line, an excellent cross section could be made. The shape of the top of the salt mass is shown on Fig. 34.

The most striking feature of the cross section is the complex graben located directly above the crown of the salt plug. This graben is formed by a set of 3 south-dipping faults, and by a set of at least 4 north-dipping faults. Each set

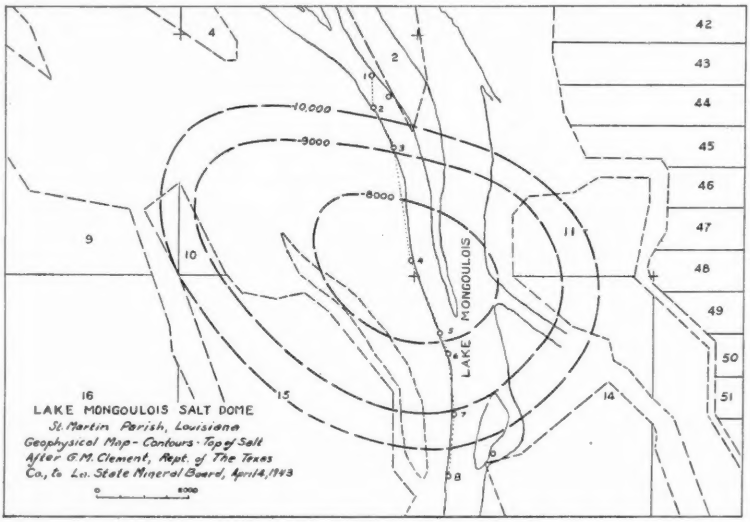


FIG. 34.—Lake Mongoulois field, St. Martin Parish. Wells numbered in cross section (all the Texas Company's State): (1) No. 8; (2) No. 6; (3) No. 9; (4) No. 1; (5) No. 4; (6) No. 3; (7) No. 10; (8) No. 11.

results in a series of successively downstepped blocks. The central downthrown block is in the form of a keystone.

Above the 7,000-foot level, the arrangement of the graben elements is, in all visible respects, similar to that found in the sections of many of the deep-seated domes. The difference between the Lake Mongoulois structure and the deeper domes lies only in the presence of the salt just below the 7,000-foot level. The salt profile shows a central crest, a steep north flank, and a more gently inclined south flank.

Of the set of 4 north-dipping faults on the south flank of the dome, the 2 lower ones extend directly to the salt. The salt shows no indication of being faulted. This suggests that these two faults developed while the head of the plug was at a lower level. Since this faulting, the salt has moved upward, cutting off the end of these faults. The two faults on the extreme south flank are probably the oldest visible in this section.

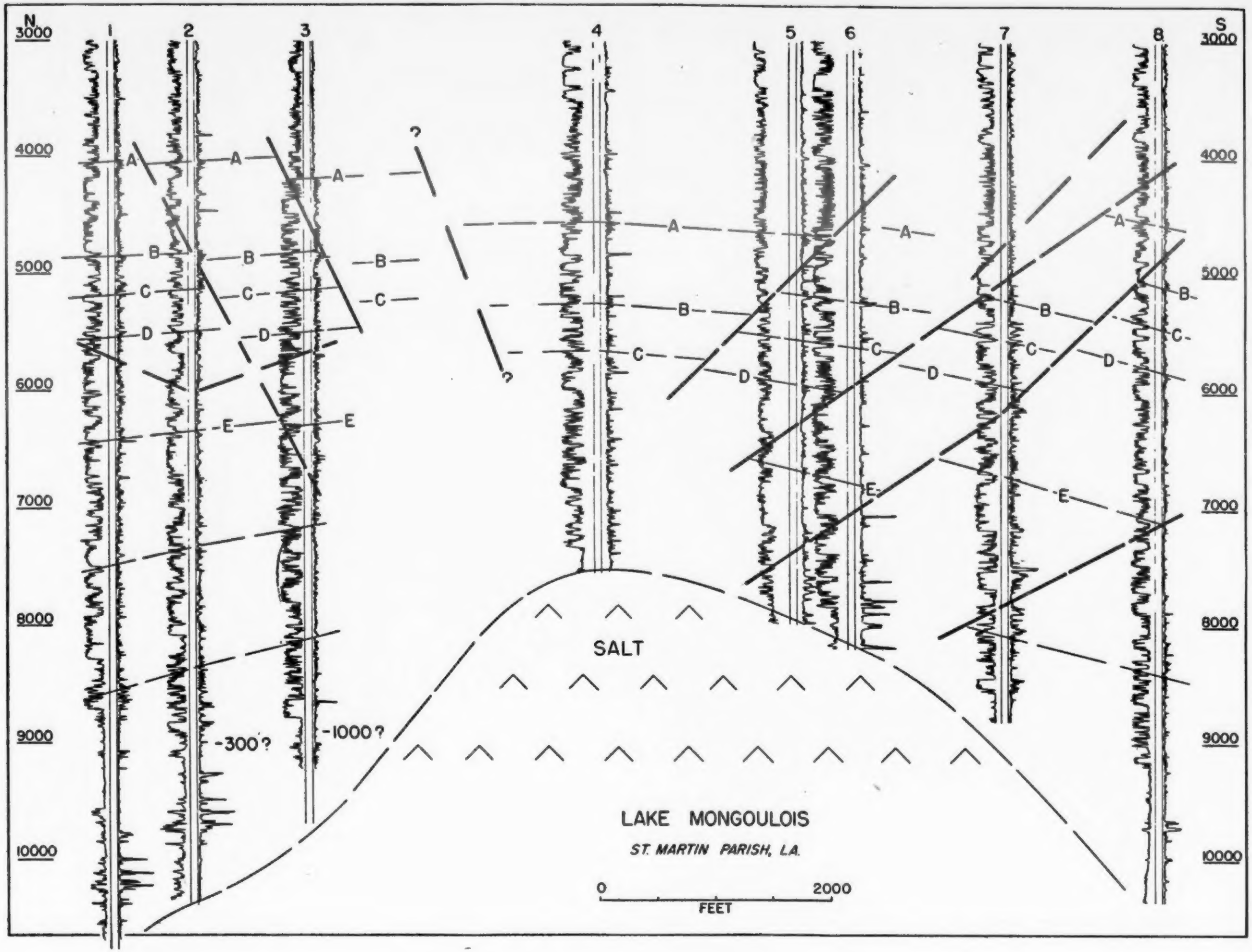


FIG. 35.—Electric-log cross section of Lake Mongoulois field.

On the north flank, there are indications of faulting near the 9,000-foot level. In well No. 3 of the section, there appears to be a loss of 1,000 feet ("−1,000?") when compared with well No. 1. Well No. 2 shows a loss of 300 feet ("−300?"). If these losses are correctly interpreted, then one or two faults must pass through wells No. 2 and No. 3 and dip north beneath the bottom of well No. 1. Such faults would have an apparent dip similar to that of the steep flank of the salt.

The faulting just described would dip in the same direction as the north-dipping set of faults on the south flank of the structure. The total combined throw of this set of faults is about 1,000 feet. This suggests that these north-dipping faults formerly crossed over the crest of the salt and were continued in wells No. 2 and No. 3.

The steep north flank of the salt profile appears to result from the extension of the north-dipping faults across the top of the salt plug. A slight upward movement has caused the salt to intersect the path of these faults.

The faults in the lower parts of wells No. 2 and No. 3 and the north-dipping set of faults were formed when the salt was pushing upward, but with a slight south component. These faults were the result of this movement. A more recent movement has been upward, but with a slight north component, resulting in the development of the south-dipping set of faults located on the north flank. These are probably the youngest faults visible in the section.

In the Lake Mongoulois section, the faults of the south-dipping set have steeper apparent dips than those of the north-dipping set. This may be the result of the greater amount of tilting which the older, north-dipping set received. This tilting would tend to reduce the dip of the faults as it increased the dip of the sediments. In the sections of Quarantine Bay and Grand Bay, the apparent dip of the lower faults is less steep than that of the upper faults. In all of the cases mentioned, the use of apparent dip offers considerable uncertainty to any interpretations of this nature.

The presence of the graben directly above the salt plug at Lake Mongoulois offers substantial evidence of the presence of the top of the salt plug directly below the grabens of all the dome-with-graben structures. Many of the sections in Part II of this article show the convergence of faults into a complexly faulted region in the deepest parts of the fields.

PART III. OBSERVATIONS AND CONCLUSIONS

FAULTS

It was observed that the number of faults was roughly proportional to the number of wells, which seems to indicate that each structure, if completely explored, would be found to contain a larger number of faults than has been recognized.

The sections prepared in connection with this report, and the accompanying maps of individual structures required recognition of depths at which individual wells are cut by faults, and estimates of the stratigraphic throw in each case.

The throw of a fault was considered to be the equivalent of the amount of

FIG. 35.—Electric-log cross section of Lake Mongoulois field.

section missing in a well. The evidence for its determination involved electrical log comparisons between near-by wells. If but one well is compared with another, there is a false precision suggested regarding the amount of section missing. The amount of loss is somewhat indeterminate when one well is compared with all of the surrounding wells. Even where two or more wells may be regarded as unfaulted, there is not perfect equivalence in thickness of each lithologic unit identified. Where faulting occurs, the determination of thicknesses becomes even more difficult. For this reason, only approximate values of stratigraphic throw can be given. The best general practice is to compare each well with all wells nearest it. Even when best practices are followed, and evidence is most precise, it is doubtful that any stratigraphic throw can be considered reliable by less than 10 feet.

Many of the small faults (50 feet or less) had to be ignored because of the extreme difficulty of tracing them with any accuracy.

No reverse faults were found associated with any of the deep-seated domes.

The dips of the principal faults were measured on several structures by solving as many as 10 or more adjacent, graphic 3-point problems across a field. The average dip was found to be about 52°, the minimum about 45°, and the maximum about 63°.

The throw of faults varies from amounts too small to measure to more than 900 feet at Roanoke. Also at Roanoke, there are two closely spaced normal faults which have a total combined throw of more than 1,100 feet. As faults have been observed to divide in several other cases, these two could be branches of a large single fault.

MAJOR OR PRINCIPAL FAULTS

The faults responsible for the more prominent dislocations are here designated as the major or principal faults. They are most easily recognized by their throws, which are measured in hundreds of feet. In simple offset domes, major faults are responsible for the inclined structural truncation. They tend to maintain their individualities at depth without ending against other faults. In dome-with-graben structures, the graben blocks are bounded by major faults.

In the St. Gabriel field, where the throw can be measured accurately in many places, it is observed that the greatest throw coincides with the highest part of the producing area and decreases in both directions along the strike. This condition is presumed to be general.

The throw of major faults decreases upward to a point of disappearance and increases downward to an unknown depth. On the Lake Mongoulois deep-seated salt dome these faults reach downward to touch the rounded top of the salt and merge with peripheral faults surrounding the salt. The horizontal extension of a major fault is roughly radial with the vertical structural axis of the dome.

The upward decrease in throw of a major fault is ordinarily gradual. It is believed, in part, to result from the absorption of the stress in the relatively unconsolidated sediments near the surface. The stress is greatest near the salt. The rate

of decrease in throw is then an approximate reflection of the sediments' ability to absorb this stress.

Major faults change in strike giving a sinuous or arcuate trace on any horizontal datum. At Barataria the direction of strike along the major fault was determined from a series of graphic 3-point problems. The fault has a gently recurving, sinuous form. The changes in strike appear to be accompanied by slight changes in dip. For example, for five calculated dips of more than 60°, the average strike was N. 74° E. For seven calculated dips of less than 60° (average 56.5°) the average strike was N. 60.5° E.

At Bateman Lake, the fault along the southwest side shows an abrupt change in strike from northwest to west. This change is accompanied by a division of the main fault into several smaller fractures.

The curved trace of the fault on some contour maps is only apparent. It is due to the projection of a trace along the intersection of a nearly plane surface and an arched sedimentary layer. Such arcs follow the general curvature of the contour lines. Even where the fault is truly plane, its trace must be curved if it intersects an arched sedimentary layer. In most cases, control is so limited that the exact strike of a fault plane can not be determined. One is then fortunate to find enough near-by wells to indicate the quadrant through which its strike must pass.

As the dip of most of the faults in deep-seated structures is about 50°, the heave is only slightly less than the throw.

MINOR FAULTS

Radial faults.—Radial faults are well known on many of the shallower domes where upturned sediments have been lifted in differing amounts around the periphery of the salt. Minor radial faulting divides the sediments above the salt into segments "like pieces of pie." Such faults are found at Gillis-English Bayou and Lake Long. Radial faults above the salt appear to result from the inability of the rock layers to withstand stretching or tension after the major faults have been developed.

Complementary faults.—In the North Crowley and Batemen Lake fields there are normal faults which differ from the major faults in that the amount of throw decreases, and even disappears at depth. These faults dip toward the major faults. At Bateman Lake a fault of this kind has a maximum throw exceeding 300 feet. The throw decreases at depth to 150 feet as it approaches the major fault. At North Crowley a similar fault has a maximum throw of 100 feet which gradually decreases and disappears downward. The upward extent of these faults is unknown. One of the structural results is a minor graben against a major fault. They are called complementary faults in this article because they are, in all known cases, associated with major faults, and their characteristics appear to be determined by that fact. The term complementary is adapted from Hamner (1939, p. 1649) who describes a small fault of this type in the Amelia field (Texas)

as "a complement to the big fault." Production is not effected by complementary faults in any of the fields so far mentioned.

The following explanation is suggested for the formation of complementary faults. Salt movement arches the sediments, resulting in the development of considerable tension in the outer competent layers of the arch. These stresses could be relieved in part by fracturing along ruptures having the characteristics of subsequent gravity faults. In the outer parts of the arc the tension is greatest, and there the throw is the greatest.

Other minor faults.—Since faults of a wide variety of lengths and throws occur, it is only possible to divide the major from the minor on an arbitrary basis.

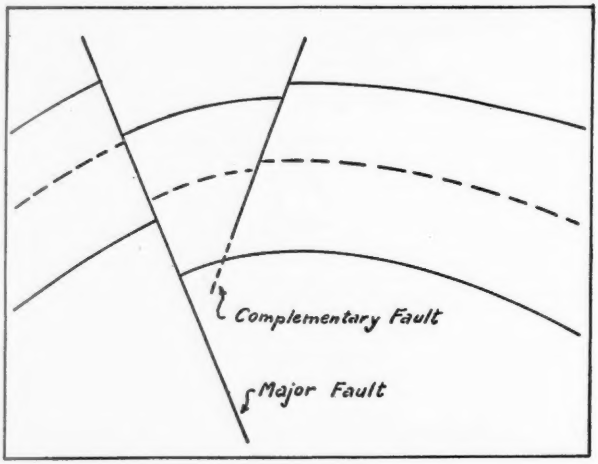


FIG. 36.—Relation of complementary fault to major fault.

It has been already pointed out that the throw on major faults decreases upward, and some major planes of displacement subdivide into smaller units. Most of the minor faults have throws of less than 100 feet. Their rôle may also be described as minor in that they make only minor adjustments in the structural pattern. They commonly occur in patterns sub-parallel with major faults, where their development might be described as auxiliary to the major faults. Most of the minor faults result from the failure of the larger faults to absorb all of the deformational stresses. When arching can be observed in detail, it is commonly noted that much of the apparent folding is actually an adjustment involving a number of small faults. With the data at hand the smaller faults ordinarily could not be followed for significant distances.

A complicated network of very small faults probably exists in the more intensely deformed parts of all domed structures, particularly near the salt mass.

The smaller faults may divide a large flanking area into small units that may

prevent the free migration of the oil updip. There are several examples of this kind on the north flanks of North Crowley and Gillis-English Bayou. In both places the productive area is extended northward because the oil could not pass freely to the highest parts of the flank.

AGE OF FAULTING AND DOMING

In the levels between 4,000 and 6,000 feet all rocks are Miocene in age in the area studied. Faults cut all of these beds. This is believed to be an indication that faulting has continued into post-Miocene time. The decreased throws at higher levels may arise for two reasons: (1) the continuation of displacement throughout the period of deposition, and (2) the absorption of stresses in the less consolidated layers.

The thinning of sediments over the crest of the structures is not readily apparent in any of the sections here given. Thinning is present on some structures not described here, notably Paradis in St. Charles Parish. Thinning would indicate contemporaneous movement. The extent of pre-Miocene displacements is necessarily indeterminate in all structures studied, because in very few places has drilling reached the base of the Miocene.

DEVELOPMENT OF DEEP-SEATED DOMES—THEORY

The story of the formation of deep domes is a little known chapter in the origin of salt domes of the piercement type. Without being too facetious it can be said that deep domes are salt domes which "never grew up."

The formation of piercement-type domes by the upward movement of a salt plug, favored by low density of salt and plasticity induced by heavy sedimentary overburden, is too well known to be discussed here. The subject of piercement domes and the mechanics of salt movement has been covered by Howe and Moresi (1931), Barton (1933), Nettleton (1934, 1943), and many others.

It is generally agreed that the salt forced itself upward with a head, commonly one or more miles in diameter and roughly circular in horizontal section. Upward movement was comparatively slow because sediments had to be ruptured and crowded aside by forces derived from slight differences in densities.

The first upward movement did not begin until a considerable load of sediments had been placed upon a thick layer of salt.

To carry the theory of salt-dome formation back to its earlier phases, we may picture the origin of deep-seated structures briefly as follows.

Step I (Fig. 37).—Following, and possibly during the deposition of the sedimentary section of the Oligocene and Miocene, slight salt movements arched these sediments. At this time, oil and gas in each sand began to migrate toward the center of the domed area. As doming became more pronounced, the oil and gas caps gradually became thicker and occupied smaller central areas.

Step II.—Continued salt movement caused the sediments to fracture or be sheared by the salt. A normal fault developed with a dip between 45° and 65°. This fault had its greatest throw near the salt. The amount of throw gradually increased over an indeterminately long period. Throw on this initial fault could

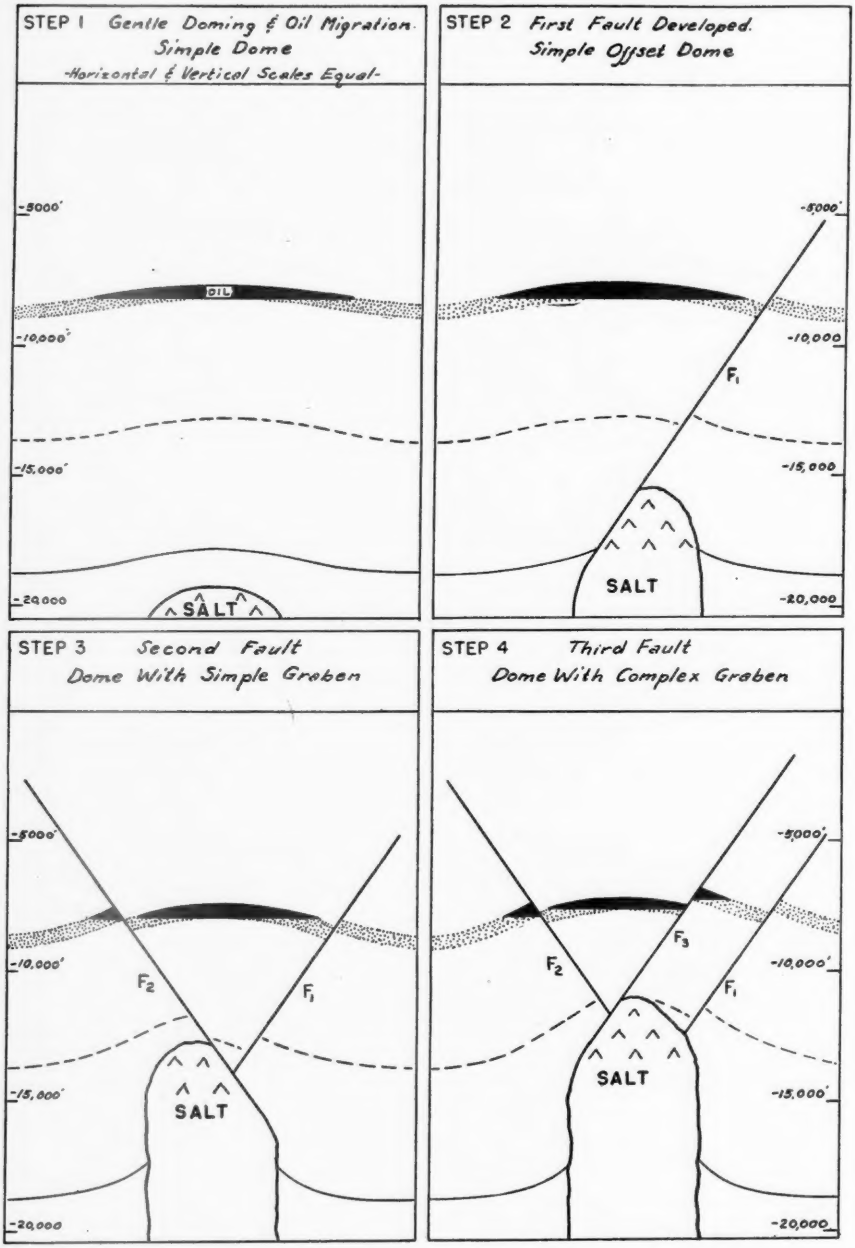


FIG. 37.—Diagrams showing origin of deep-seated structures.

not be increased indefinitely, because it required a force with a greater horizontal component than the upward-moving salt provided. All forces tending to move the salt have their maximum efficiency when the movement is vertical.

Step III.—The first major fault was not capable of relieving all stresses caused by the upward movement of the salt. Stresses in the upthrown block increased its throw. Stresses in the downthrown block ultimately led to a second rupture, a normal fault whose direction opposed that of the first major fault. The throw increased under limitations duplicating those of the first fault.

Step IV.—If upward movement of the salt continued, a third fault would be formed roughly parallel with, and vertically above, the first fault. A third major fault of this kind is commonly noted in connection with grabens, and it is this fault which first compounds the graben. A fourth or even more faults have developed later, first on one side, then on the other.

The process so far detailed is progressive. With continued movement of the salt, earlier faults passed to lower positions in relation to the head of the salt column, their lower ends abutting the flank of the salt. In section, these by-passed faults have the anomalous appearance of reaching the salt where they end abruptly (see section of Lake Mongoulois, Fig. 35).

If salt cores could rise under conditions of perfect confinement on all sides, they would cause a conical distribution of maximum stress in the rocks above them. Rupture under such conditions would produce a conical fault with a circular surface trace. The apical angle of the inverted cone would be about 90° and the dip of the fracture about 45°. Such a hypothetical cone is not actually created because the strength of the materials is not sufficient to bear the burden of the cone and because the salt does not rise under conditions of complete horizontal confinement.

Certain variations from the simplified conditions of salt rise are to be anticipated. Tendencies toward deflection of the salt from its vertical path are present. The mass always seeks to overcome them. The regional dip tends to promote deflection as do irregularities in sedimentation or structural weaknesses of any kind. The presence of folds or fractures caused by agencies other than local salt movement would certainly influence the mechanics of fracture development caused by the rising salt. The linear or gently sinuous fault strikes actually observed are a wide departure from the ideal fractures that conical stresses would create.

There is little doubt of considerable variation in the size as well as the shape of the original head of the rising core. This may account for some of the variations in the area involved in single deep domes.

The minor faults have been ignored in the discussion of theory. Their rôle is believed to be more or less incidental to the general adjustment provided by the major fractures.

The possibility of collapse as an explanation of the formation of grabens must be considered. In fact, to persons familiar with shallower salt domes, it seems to be the logical explanation. Collapse on shallower domes has been established

beyond a doubt. In the deep structures, the inability of waters to circulate in deeper sands removes the only method by which the salt could be removed and a mechanism for collapse provided.

In theory here outlined, attention has been directed particularly to deep dome-with-graben structures. The same explanation apparently fits the simple offset dome. Here a single fault passes diagonally through arched sedimentary beds. This fault may be the uppermost in a possible series, the others of which are at lower levels. This type of structure would be created by the latest fault to be developed and represents practically the upward limit of deformation. In general, further exploration may be expected to reveal other faults on any given structure of this type, and to cause it to be reclassified as a dome-with-graben.

Complexly offset domes such as Grand Bay and Grand Lake are only explored on one flank. The resemblance to certain parts of the graben structures leads to the conclusion that exploration of the opposite flank will reveal opposing faults and a complete graben.

Other types of deep-seated domes, for the most part, are but incompletely known at present. Whether they represent larger and more complicated forms of the graben structure, a combination of effects between salt uplift and regional faulting, or division of salt cores, remains to be determined.

ACCUMULATION OF OIL AND GAS

General.—The structures with single major faults may have an accumulation of petroleum on either the upthrown side of the structure (Barataria), the downthrown block (Tepetate), or on both sides of the fault plane (North Crowley). It is not exceptional to find producing sands low in a centrally domed area, and to find that a fault with several hundred feet of throw has lifted a dry flank high above it. This condition is recognized as usual.

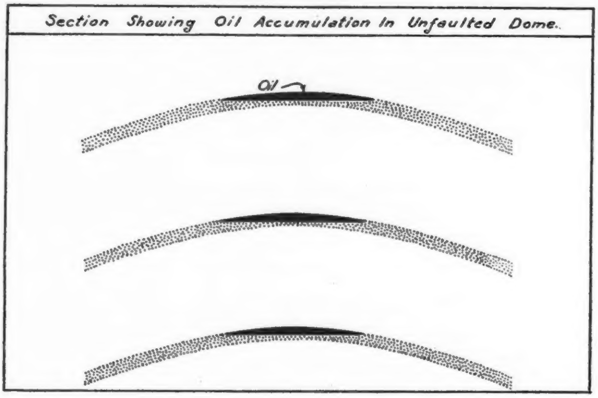
Where the known part of the structure consists of a pair of similar faults as at Grand Bay, oil is commonly found along the upthrown sides of each fault.

The gaben structures produce from traps along fault planes. In Gillis-English Bayou, traps occur along both the north and south flanks. Within the graben, each separate block has oil in the highest part of the block along dividing faults. On the north flank, very minor faulting has interrupted migration upward to the crest of the flank and has extended the producing area into territory farther down the flank.

The Barataria field presents a somewhat exceptional type of accumulation in that the oil is produced from the upthrown side of a fault of comparatively small throw and low structural relief. In this case the fault is probably not only responsible for the trap in preventing further movement, but is also responsible for tilting beds which were nearly horizontal and providing a mechanism for migration. The accumulation of oil at Gibson is also probably a result of faulting rather than a result of doming. Slight structural relief is an indication of the great depth of burial of the salt plug in both structures.

The outline of accumulation just presented is a simplification of very compli-

cated conditions. The complications of distribution of trapped oil and gas are legion. The productive sands occasionally number six or more. They are commonly separated by considerable vertical intervals. Sands productive in one block are not necessarily productive in others. The lensing of sands is conspicuous.



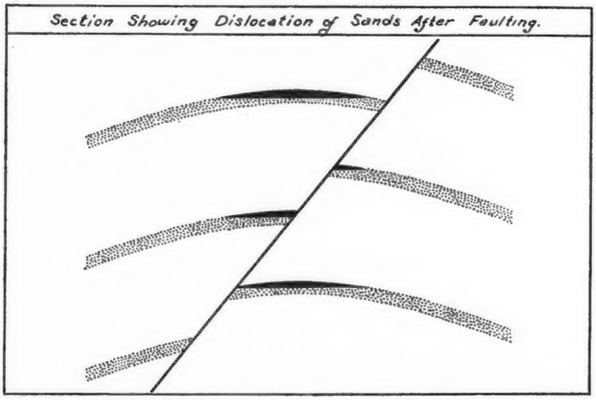


FIG. 38.—Sections showing accumulation of oil before and after faulting.

ACCUMULATION THEORY

It is not within the scope of this report to delve into any controversy as to the manner of origin of petroleum and gas. However, in order to explain the accumulation of these substances in the rocks of deep-seated domes, the matter of origin must be given some consideration.

The idea that petroleum develops from organic matter buried along with marine and brackish-water sediments, and that with slight deformation, the dis-

persed petroleum and gas will slowly migrate, because of their lesser densities, through the connate water to higher structural positions, is accepted.

In the homoclinally tilted rocks of south Louisiana, there might be a tendency for general migration to take place northward up the regional dip. As the amount of dip is generally small, and no greater accumulation is noted on the south than on other flanks of domes, regional migration in Miocene sediments is considered unlikely.

More likely is the migration of oil and gas to the centers of areas domed by earlier, upward movements of the salt. This migration would start with the initial development of the dome and would continue to completion unless interrupted by faults or other barriers. The volume of oil would bear a direct relation to the contributing area, which is the entire structure to its outermost flanks.

If faulting occurs after the movement of the oil to the crest of the dome, it will divide the reservoir into segments. As the faults pass diagonally through the structure, the upper sands should retain the original accumulation intact on the downthrown side, and the accumulation in the lower sands should remain intact on the upthrown side (Fig. 38). In intermediate positions, the area of accumulation should be divided, the crown being some distance from the fault on the downthrown block and the accumulation being against the fault on the upthrown block.

With additional faulting, the original reservoir should be further subdivided. The original accumulations should remain in the sands except for these possible causes of migration: (1) the tilting resulting from further deformation and faulting may cause migration; (2) the opportunity to escape upward along the fault surfaces may be present; and (3) escape into adjacent sands that happen to be brought into position by faulting may be possible.

In general, the oil originally accumulated in a juvenile and unfaulted dome should maintain its approximate geographic position regardless of any faulting which might take place later. In other words, the original accumulation remains roughly intact, despite its segmentation by faults.

The faults are the principal clues to the traps on deep-seated domes. Not only do they provide the barriers against which most of the oil is trapped but the nature of the faulting itself increases the dip of the strata and promotes migration toward the faults. At Barataria and Grand Lake fields the accumulation seems to result almost entirely from slight doming which has resulted from the faulting process alone.

PART IV. SUMMARY OF CONCLUSIONS

The salt domes of the Gulf Coast salt-dome belt in Louisiana are all members of a series grading from those with the salt in a position near the surface to those in which the top of the salt has not been reached by the deepest wells. The series may be divided arbitrarily on the basis of depth to the top of the salt. In this investigation, primary consideration was given to the deep-seated domes. Electrical logs from wells offer the most valuable single source of information now available for structural studies of this kind.

The greatest number of wells are located on the more intensely deformed parts of the structures. The marginal, unexplored areas include the outer flanks of the domes.

All of the domes investigated contain faults. The number of faults found is roughly proportional to the number of wells. This seems to indicate that each structure, if completely explored, would be found to contain a larger number of faults than has yet been recognized.

The characteristic structure consists of a gently domed area broken centrally by a complex graben. Evidence derived from a deep-seated salt dome (Lake Mongoulois) suggests that a graben lies directly above the salt plug in all deep-seated domes.

A second type of deep-seated dome contains one or a group of faults with similar strikes and directions of dip. This type may be described as a simple offset dome. Further exploration will probably reveal other faults with opposing dips to complete a graben.

All observed faults were of the normal or gravity type. The dip and throw of a number of faults were measured. Dips ranged from 45° to 63° and throw varied from amounts too small to be measured to more than 900 feet.

The throw of the faults on a dome is an indication of the amount of vertical deformation. The structural relief may thus be approximated from measurements of the throw of the major faults.

Faults on deep-seated domes may be divided into two general types, major and minor. The major faults have throws of several hundred feet and cause the principal structural dislocations. The throw of a major fault decreases in all directions away from its contact with the salt.

Minor faults are so called because they take a minor part in the segmentation of deep-seated domes. Two distinctive types are recognized.

Radial minor faults extend radially from the center of doming and tend to divide the flanks of the dome into segments like "pieces of pie."

Complementary minor faults are distinctive in that the throw decreases downward. Such faults dip toward major faults and result in the development of small grabens against major faults. The maximum throw of a complementary fault may be as much as 300 feet. The amount of throw decreases rapidly as the major fault is approached. Complementary faults relieve tension in the outer, uparched layers of the dome.

Other minor faults are less readily classified. They may be parallel and close to major faults, or they may be branches or small subdivisions of major faults.

Many minor faults are too small to be traced by means of electrical logs.

The extent of pre-Miocene displacement could not be determined. Some displacement probably occurred during the Miocene, but the principal movements appear to have taken place in post-Miocene time.

The most prominent faults on a single structure commonly have a similar direction of strike.

Deep-seated domes are developed by the upward movement of a salt plug

which first causes the deeply buried layers to be gently domed. Continued salt movement causes rupture in the form of a major, normal fault extending diagonally upward through the dome from the head of the salt plug.

Additional salt movement causes additional faults of the same kind but directed alternately opposite to, and parallel with, the first fault. The result is a complexly faulted graben with the later faults at higher levels within the graben.

It is concluded that the salt lies only a short distance below drilling depths in domes showing convergence of several faults with opposing dips. Convergence of faults just above the salt at Lake Mongoulois supports this conclusion.

The present distribution of oil and gas on deep-seated domes is the result of at least two sets of conditions. The present general location of the oil and gas is related directly to the center of the original gentle dome created by the earlier movements of the salt. Into this simple domal trap, petroleum migrated from the entire deformed area of the dome.

The specific location of each individual trap for each sand is now dependent on the segmentation of the dome by faulting. In general, the petroleum will remain in its original geographic location, but with many complications added by the barriers developed by faulting and the further tilting of faulted blocks.

Faults, extending outward into strata which are only very slightly arched, increase the dip of these layers and promote increased drainage of oil toward the fault. This probably accounts for production in fields such as Barataria and Gibson.

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VOL. 28, NO. 9 (SEPTEMBER, 1944), PP. 1313-1354, 1 FIG.

OLIGOCENE STRATIGRAPHY OF SOUTHEASTERN UNITED STATES[1]

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ABSTRACT

Preliminary notes on a detailed study of the eastern Gulf Oligocene are here presented. "Vicksburg group," a term formerly used by the United States Geological Survey to include all Oligocene deposits in this region, is restricted to a middle part of the Oligocene, namely, the Marianna limestone and the Byram formation. The Glendon limestone and Bucatunna clay are treated as members of the Byram formation. The Red Bluff clay and Forest Hill sand are regarded as lower Oligocene; the Chickasawhay limestone, here restricted to the "Lower Chickasawhay" of the *Guidebook* of the Eleventh Annual Field Trip of the Shreveport Geological Society, the Suwannee limestone,[3] and the Flint River formation are regarded as upper Oligocene. The "Upper Chickasawhay" of the *Guidebook* is here renamed the Paynes Hammock sand, with the type locality at Paynes Hammock, on the Tombigbee River in Clarke County, Alabama, and is regarded as basal Miocene. The Paynes Hammock sand intertongues at the west with non-fossiliferous beds referred to the Catahoula sandstone, with the Paynes Hammock tongue below the Catahoula tongue. The Paynes Hammock sand and equivalent beds on the west referred to the Catahoula sandstone are correlated with the Tampa limestone.

INTRODUCTION

In connection with a project to monograph the large molluscan fauna of the formations of the middle and lower Oligocene of the southeastern United States, the writer undertook to make a detailed stratigraphic and lithologic study of that part of the section lying between the Ocala limestone below and the Alum Bluff group above in Florida, and between the Yazoo clay below and the equivalent of the Alum Bluff group, if it could be determined, in western Alabama and Mississippi. In addition to the Vicksburg group, as restricted in this paper, the Oligocene is made to include in the lower part the Forest Hill sand and the Red Bluff clay, and in the upper part, in Mississippi and Alabama, the lower part of the Chickasawhay marl, as formerly recognized by the Geological Survey, and, in Alabama and Florida, its equivalents, the Flint River formation and Suwannee limestone.[3] This study corroborates a recently proposed correlation of the upper

[1] Published by permission of the director of the Geological Survey, United States Department of the Interior. Manuscript received, February 28, 1944.

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[3] It was the writer's belief at the time this paper was written that the Suwannee limestone was the exact equivalent of the Chickasawhay limestone, and all references to it are in that sense. More recently, however, the age of the lowest beds of the Suwannee limestone has been seriously questioned. Herman Gunter and Sidney Stubbs in a paper delivered before the Mississippi Geological Society in 1941 reported that of 153 feet of Oligocene penetrated in a water well at Tallahassee, the upper 111 feet carried a Flint River fauna and the lower 42 feet carried the *Coskinolina cookei* fauna typical of the lower part of the Suwannee limestone. They favored calling the lower 42 feet Suwannee limestone and the upper 111 feet the Flint River formation, the Suwannee being possibly of Byram age.

In 1942 Robert O. Vernon (*Florida Geol. Surv. Bull. 21*, p. 56) pointed out that Bryozoa, Foraminifera, Ostracoda, and Mollusca studied from the Suwannee limestone of Holmes and Washington counties indicate that both the Byram and Chickasawhay formations are represented. It was his opinion that mappable units could not be differentiated and that the Suwannee limestone should be emended to include the equivalent of the Byram in Florida.

The Suwannee limestone as originally defined includes beds exposed along the Suwannee River from Ellaville nearly to White Springs. The equivalent of the Flint River formation and the Chickasa-

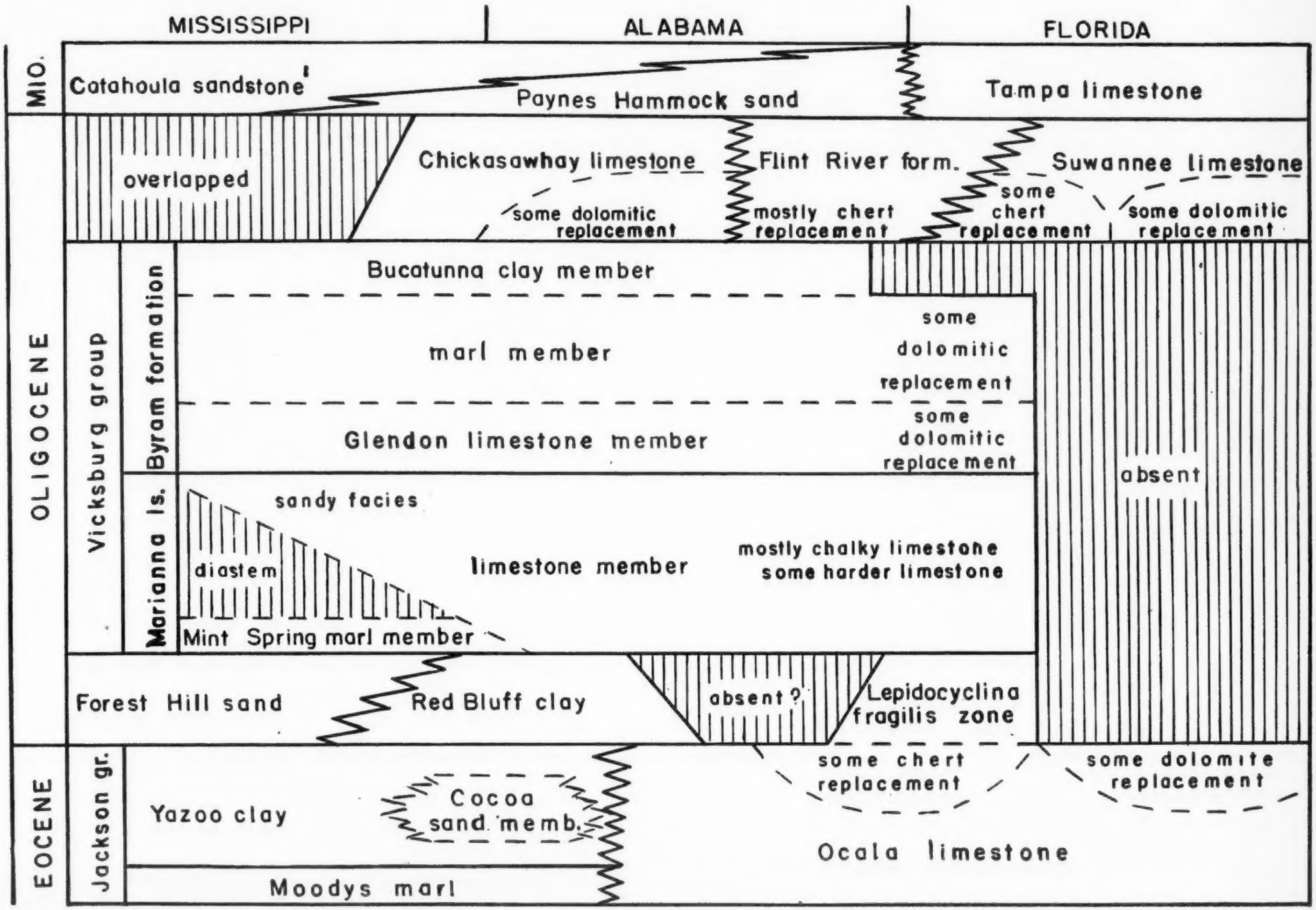
part of the Chickasawhay marl, as formerly used by the Geological Survey, with the Tampa limestone of Florida. The location of the Oligocene-Miocene boundary in this paper is based on the current practice of the Geological Survey to classify the Tampa limestone as basal Miocene. Some workers have contended that the Miocene should be expanded to include the Chickasawhay limestone and even the Bucatunna clay member of the Byram formation, and others that the Oligocene should be expanded to include the Catahoula sandstone and the Tampa limestone. The final solution to this problem is not imminent, and depends first on the decision as to where to place the boundary in Europe, about which there is as wide disagreement as in this country, and second on the difficult and uncertain process of trans-Atlantic correlation. It might be said in this connection, however, that the primary divisions of the Tertiary are based on marine molluscan faunas of the European section and the only correlations that can be made must be with the units as delimited by those faunas, whether on the basis of Mollusca or some other group of organisms. Local or even regional disconformities in other parts of the world have nothing whatsoever to do with it. It is extremely improbable that all or even a good part of the earth's crust was affected by the same diastrophism. It would be coincidence entirely if any depositional break in the Gulf Coastal Plain should correspond with a break at the same place in the European section, and it is probable that the European breaks actually fall within formations as they are delimited in this country. The placing of the Oligocene-Miocene boundary at the exact base of the Tampa limestone, or at any other horizon, is, therefore, extremely arbitrary.

To date this study has been carried out in detail from Vicksburg, Mississippi, to south-central Alabama, and in reconnaissance to the Florida Peninsula, completion of the work having been delayed by the war. Owing to recent intensive geological activity in southeastern Mississippi, however, and the demand for any

whay limestone is almost certainly included in the higher beds exposed. The most accessible, and certainly the best known exposure, and the one commonly regarded as the type locality, however, is that below the bridge at Ellaville. The basal beds of the Suwannee limestone at this place rest on porous, cream-colored limestone carrying a lower Oligocene fauna. Only two species are mentioned in the original description of the Suwannee limestone. One is *Coskinolina cookei*, a foram of local occurrence at this horizon, and which some geologists believe was reworked from the Claiborne, and which has never been reported from any Oligocene horizon in Alabama or Mississippi. The other species is *Cassidulus gouldii*, an echinoid once believed to be confined to the upper Oligocene. This species has more recently been found by the writer to occur abundantly at several localities in the Mint Spring marl in Mississippi.

It seems, therefore, that paleontologic evidence for dating the lowest beds of the Suwannee limestone is lacking. It is probable that the basal beds of the Suwannee limestone are of Byram or possibly of Marianna age. In this event, the Suwannee limestone should either be redefined to include the Byram, in which case it might be of value where the Byram and Chickasawhay equivalents are not separable lithologically, or it should be abandoned. The writer now feels that too many names are in use for the equivalents of the Chickasawhay limestone in the southeast. Chickasawhay limestone could well replace Flint River formation, and unless Suwannee limestone is emended to include the Byram, it could well replace that name as well.

The Flint River formation probably does overlap the lower and middle Oligocene beds in Georgia, but recent work by the writer has shown that it does not overlap the Jackson nearly so much as was once supposed, if at all. The residuum of the Ocala has been detected nearly everywhere at the base of beds mapped as Flint River.



[1] Lower part of Catahoula. Upper part of Catahoula may be Alum Bluff in age.

FIG. 1.—Correlation of Oligocene deposits of Mississippi, Alabama, and Florida.

information relating to the stratigraphy of the region, the following preliminary notes and correlations are offered.

GENERAL FEATURES OF OLIGOCENE DEPOSITS

The formations and members of the eastern Gulf Oligocene as here recognized are as follows.

Chickasawhay limestone	Flint River formation	Suwannee limestone[3]
Disconformity		
Vicksburg group		
Byram formation		
Bucatunna clay member		
Marl member		
Glendon limestone member		
Marianna limestone		
Limestone member		
Mint Spring marl member		
Disconformity		
Forest Hill sand	Red Bluff clay	*Lepidocyclina fragilis* zone

The three youngest formations, the Chickasawhay limestone, the Suwannee limestone, and the Flint River formation, although retained in the Oligocene, are here excluded from the Vicksburg group, thus differing from previous Geological Survey usage. The two underlying formations, the Byram formation, including its two named members, the Bucatunna clay member and the Glendon limestone member, and the Marianna limestone, with its Mint Spring marl member, are made to constitute the Vicksburg group.[4] The Vicksburg is thus made to include only the beds for which the name was originally intended, namely, the fossiliferous Oligocene of Warren County, Mississippi. The basal formations, the Forest Hill sand and the Red Bluff clay, believed to be definitely Oligocene, are also excluded from the Vicksburg group. The restriction of the term Vicksburg group to a middle portion of the Oligocene is not a new idea, various geologists having suggested that the top or bottom, or both, of the Oligocene be removed from the Vicksburg, and some having gone so far as to regard, as previously stated, the upper part as Miocene and others to regard the lower part as Eocene.

The formations of the Vicksburg crop out in a moderately narrow band extending from Vicksburg, Mississippi, to about midway of the Florida-Alabama State line. Farther southeast for an interval of about 50 miles, in which they are believed to be partly covered by younger beds, a few scattered outcrops of as yet unsatisfactorily determined age are known. Beyond this interval the Marianna limestone again crops out in many excellent exposures in the vicinity of Marianna, Florida, but beyond exposures just east of the town of Marianna no further ex-

[4] The restriction of the Vicksburg and the inclusion of the Glendon limestone in the Byram formation was accepted by the Committee on Geologic Names of the Geological Survey as a result of a previous draft of this paper submitted in 1941. The paper was recalled for changes and as a result this revised classification first appeared in a correlation chart by C. Wythe Cooke, Julia A. Gardner, and Wendell P. Woodring in the *Bulletin* of the Geological Society of America, Vol. 54, pp. 1713–22, November 1, 1943.

posures are seen and it has not been recognized in wells on the east. The Byram formation is definitely known to occur at the Natural Bridge just south of the Alabama-Florida State line, about 7 miles east of Florala, Alabama, and limestone exposed in a sink in the SE. ¼ of Sec. 3, T. 4 N., R. 17 W., Holmes County, Florida, also appears to be Byram. The Marianna limestone in the vicinity of Marianna, Florida, is overlain by a dolomitic replacement of harder ledge-forming and softer interbedded limestone, probably the Glendon limestone member of the Byram formation. A zone of high-grade bentonite several feet above the base of the dolomite is also included in the Glendon and probably corresponds with bentonite in the Glendon in Smith County, Mississippi. Higher, and exposed for some distance south along the Chipola River, is a section of homogeneous dolomite. This has been identified as Byram in the past to a point as far as 14 miles south of Marianna. It is likely that the greater part of this dolomite is a replacement of the soft, porous limestone such as is exposed in the well known sink at Duncan Church, 7 miles southwest of Chipley, and the lower limestone seen in the sink back of the A. L. Parrish farmhouse in the SW. ¼, SE. ¼ Sec. 33, T. 3 N., R. 13 W., Washington County, Florida, which at these localities has been referred to the Suwannee limestone, but which is probably of Byram age.

The occurrence of several feet of middle Oligocene limestone between undoubted Ocala limestone and the Suwannee limestone as at present delimited along the Suwannee River at Ellaville, Florida, is open to question. This interval was referred to the Glendon limestone in the *Twentieth Annual Report* of the Florida Geological Survey and was so mapped on the geologic map accompanying that report, but as many of the mollusks in this bed are undescribed its exact position in the section is still to be definitely determined.[5] Mansfield[6] reported that a *Lepidocyclina* from this bed had been identified by T. W. Vaughan as *L. supera*, a specimen common in the Byram formation. Both the original material and additional material collected by the writer, however, have since been identified by Vaughan as *Lepidocyclina georgiana*, an Ocala species.

Of the upper Oligocene formations, the Chickasawhay limestone is not exposed over a widespread area, being restricted to a band of strike outcrops in

[5] Work on this fauna since the preparation of this manuscript has shown that most of the mollusks in this bed are Mint Spring species. One species occurring abundantly in this bed, however, *Turritella martinensis*, has not been found in the Mint Spring itself, but it does occur in Mississippi in the upper few feet of fine clayey sand of the Forest Hill that characteristically carries a Mint Spring rather than a Red Bluff fauna. *Turritella martinensis* also occurs abundantly in a hard white basal ledge of the Oligocene in the large quarry about 6 miles southeast of Crystal River, Citrus County, Florida. *Turritella martinensis* was described from a now abandoned and poorly exposed quarry at Martin Station, Hernando County, Florida, from a horizon believed to be high in the Ocala limestone. It now seems probable that the *Turritella martinensis* zone is basal Oligocene, but whether the species ranges downward into the Ocala limestone has not been definitely determined. *Lepidocyclina georgiana* which almost everywhere in Florida is associated with *T. martinensis* may also be Oligocene. The *Turritella martinensis* zone is tentatively correlated with the Forest Hill sand, although it may prove to be a deep-water facies of the Marianna limestone. The possibility that it is Byram, as has been assumed in the past, is unlikely.

[6] W. C. Mansfield, "Mollusks of the Tampa and Suwannee Limestones of Florida," *Florida Geol. Survey Bull. 15* (1937), p. 47.

southeastern Mississippi and southwestern and south-central Alabama. Its equivalents, the Suwannee limestone and the Flint River formation, however, cover large areas in northern and western peninsular Florida, in southeastern Alabama and adjoining Florida, and in southwestern and central Georgia; and an outlier of the Flint River formation occurs along the Georgia-South Carolina State line. Westward the Chickasawhay and Vicksburg are progressively overlapped by the Catahoula. The Chickasawhay limestone is not definitely known west of Eucutta in northwestern Wayne County, Mississippi.

The lower Oligocene Red Bluff clay passes into soft calcareous limestone in Alabama and has been traced continuously as far east as Monroe County. Beyond that, if present, it is not separable lithologically from the Marianna limestone, although some faunal criteria may be found to separate it. Around Marianna, Florida, however, a zone of crumbly limestone containing abundant *Lepidocyclina fragilis* lies between the soft Marianna limestone and the Ocala limestone. This zone has hitherto been assigned to the Ocala limestone. The *Lepidocyclina fragilis* zone is correlated with the Red Bluff clay. The outcrop of the Forest Hill lies north of and roughly parallels the outcrop of the Vicksburg group in a somewhat broader band from Vicksburg, Mississippi, in eastern Jasper County, Mississippi, where the lower part interfingers with the Red Bluff clay. The upper part continues to about the Mississippi-Alabama State line, where it begins to thin rapidly and is included in the Red Bluff.

The Oligocene formations are involved in the surface expression of at least three of the well known structural features of the Gulf Coastal Plain, the Jackson fault, the Hatchetigbee anticline, and the Jackson dome, and they have provided the main surface indication of at least two salt domes recently discovered in western Mississippi. The first two producing wells in eastern Mississippi, located in the northwestern part of Wayne County and in southeastern Jasper County, respectively, are in regions of Oligocene outcrop. Lithologically the sediments of this epoch are made up of lignites, bentonite, clay, sandy clay, sand, sandy and glauconitic limestone, and pure chalky to hard limestone. The conditions of deposition ranged from lagoonal and deltaic to moderately deep, quiet marine.

FOREST HILL SAND AND RED BLUFF CLAY

The Forest Hill sand, named by Cooke from Forest Hill School, $5\frac{1}{2}$ miles southwest of Jackson, Mississippi, is a typical deltaic type of deposit. It consists mainly of sand and thinly laminated sand and clay, usually with minor cross-bedding but more rarely with strong cross-bedding. Some coarsely laminated clay is also to be found. Both the lowermost and uppermost parts commonly contain beds of lignite, a bed more than 3 feet thick forming the top of the formation at one place along the Leaf River in Smith County, Mississippi. Except for lignite, the Forest Hill sand is generally unfossiliferous, although poorly preserved prints of shells occur in beds of Forest Hill type lithology in

the region of transition between it and the Red Bluff clay in eastern Jasper County, Mississippi. The uppermost few feet of the Forest Hill frequently carries Mint Spring mollusca, either scattered, or concentrated along thin sand partings. At one place on the Chickasawhay River a bed of clay containing well preserved leaves occurs near the top of the Forest Hill. In central and western Mississippi the Forest Hill ranges from 75 to 100 feet in thickness, but it begins to thin rapidly near the Alabama line.

The Red Bluff clay, named by Hilgard from a bluff on the Chickasawhay River just above the railroad bridge, $1\frac{1}{2}$ miles south of Shubuta, in Wayne county, Mississippi, consists of clay, glauconitic clayey marl with hard limestone ledges, and chalky limestone. Ferruginous streaks and concretions are common. Marine fossils occur in all exposures of the Red Bluff clay examined and in the region of the type locality the fauna is extremely rich. Its maximum thickness is about 30 feet.

Cooke[6a] originally regarded the Forest Hill sand as contemporaneous with the Red Bluff clay, but later[7] accepted the view of a group of Gulf Coast geologists[7a] that the Red Bluff comes in from the east as a wedge between the Yazoo clay and the Forest Hill sand. The base of the Forest Hill appears to be barren of fossils in eastern Jasper County in the vicinity of Vosburg and Stafford Springs, although one good exposure was seen and several auger holes were drilled through the contact. *Ostrea vicksburgensis* Conrad was reported to have been found at the base of the Forest Hill at an unnamed locality near Paulding, Jasper County, Mississippi. Good exposures of the base of the Forest Hill can be seen at several places near Paulding, but at all places examined by the writer it is unfossiliferous. The top of the Jackson in this vicinity, however, contains *Gryphaeostrea subeversa* Conrad. At least two horizons well up in the formation, however, contain prints of shells, suggesting that the Red Bluff interfingers with at least the lower part of the Forest Hill rather than wedges beneath it. One such locality is a road cut on U. S. Highway 11, 2 miles northeast of Stafford Springs. Prints occur in clay laminae of a 5-foot zone of coarsely laminated sand and clay. An auger hole drilled at the base of this exposure failed to penetrate the Yazoo clay at a depth of 18 feet. A zone of cream-colored calcareous concretions containing prints of mollusks, one of which, a large *Arca*, appears to be unique to this locality, occurs between laminated sand and clay in the road cut at a small church in the north-central part of Sec. 4, T. 10 N., R. 10 W., Jasper County. Unless this exposure is greatly out of place owing to faulting, this fossiliferous bed is well up in the Forest Hill sand.

The location of the base of the Red Bluff in the vicinity of Hiwannee, Missis-

[6a] C. W. Cooke, "Correlation of the Deposits of Jackson and Vicksburg Ages in Mississippi and Alabama," *Jour. Washington Acad. Sci.*, Vol. 8 (1918), p. 193.

[7] ———, "Notes on the Vicksburg Group," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), p. 1163.

[7a] Shreveport Geological Society, *Eleventh Annual Field Trip* (1934), p. 9 (Steffey reprint).

sippi, is subject to two interpretations. An excellent, unweathered exposure can be seen just below a bend in the Chickasawhay River in the SE. ¼ of Sec. 29, T. 10 N., R. 7 W., about 1 mile southwest of Hiwannee Station. The writer places the contact at this locality at the base of a 3½-foot bed of glauconitic gray clay overlying non-glauconitic greenish Yazoo clay, and overlain by a 1½-foot bed of glauconitic marl in which calcareous concretions up to 1½ feet in length occur. An abrupt change in fauna takes place at the base of the glauconitic zone, the greenish clay below containing a *Flabellum* and a large *Acteon* as its most abundant macrofossils, whereas with the appearance of the glauconite, *Balanophyllia* and *Archohelia* and several large Red Bluff gastropods immediately occur. The upper level at which the contact could be placed, and has been placed by some workers, is the base of the overlying sandy marl bed just above which calcareous clay balls riddled by boring pelecypods occur. Borings more than an inch in diameter filled with calcareous marl extend below the marl bed into the glauconitic gray clay bed with Red Bluff fossils both within and without the borings. Small borings less than the thickness of a pencil in diameter extend from the glauconitic gray clay into the non-glauconitic greenish clay, which, however, contains Red Bluff fossils, whereas the surrounding greenish clay contains Jackson fossils only.

Calcareous clay balls riddled by boring pelecypods, identical with those here recorded from the Red Bluff, were described by Stenzel[8] from the Moodys marl at Creole Bluff, Louisiana, and were regarded by him as constituting a basal conglomerate of the Moodys marl. As described later, identical clay balls occur in the Mint Spring marl member of the Marianna limestone, mainly at the base of the fossiliferous sand, but also scattered and isolated well up in the sand, and at the base of the limestone member as well. The writer does not agree with Stenzel that these clay balls mark an unconformity or even should be classified as a conglomerate in the same sense that quartz and granitic pebbles are so regarded. Rather, they appear to be small masses of clay or marl obtained close at hand, neither subjected to or capable of withstanding much abrasion. They may occur at formational contacts, but they may occur intraformationally as well.

The sequence of sediments across the Yazoo-Red Bluff contact near Hiwannee is essentially the same as that described by Stenzel for the Yegua-Moodys sequence at Creole Bluff. In both sequences an abrupt appearance of glauconite accompanies a change of fauna. At Creole Bluff a characteristic fauna appears in beds that rest on a barren interval, and at Hiwannee a new fauna replaces that of the beds below. Several feet above the base of the glauconitic zone in both sections a much more striking lithologic break occurs. In both sections this break lies between a highly fossiliferous sandy marl above and a less fossiliferous clay below, with an accumulation of bored clay balls at the base of the sandy marl. A number of geologists have presented evidence that abrupt or extensive accumulations of glauconite indicate breaks in stratigraphic succession, probably as

[8] H. B. Stenzel, "The Yegua Problem," *Univ. Texas Pub. 3945* (1940), p. 862, Pl. 50.

periods of slow deposition or non-deposition, a review of this evidence having been published by Goldman.[9] It is possible that the lower glauconitic clay described in the sections mentioned represents a period of slow deposition from the beginning of the new submergence represented by the base of the glauconite zone to the time of the arrival of the basal sands of the new formation at this point down the dip. Thus in a sense they are transitional beds. Whatever the explanation for contacts of this type, something fundamental is involved, as this same sort of sequence can be seen in many places in downdip coastal plain contacts.

The Red Bluff clay, which grades laterally into or interfingers with the lower part of the Forest Hill sand on the west, grades vertically into typical Forest Hill sand in the vicinity of Hiwannee. A set of closely spaced samples showing this gradation was obtained from a well dug on the property of A. D. Williams at Hiwannee in 1939. The lowest sample obtained was of a glauconitic fossiliferous clay 1½ feet below a 1½-foot bed of calcareous glauconitic sandy marl containing large calcareous concretions that corresponds with the marl bed on the Chickasawhay River previously described. The base of the section represented by samples from the well, therefore, can be confidently placed at about 2 feet above the base of the Red Bluff, as here interpreted. Above the concretionary marl bed lies a stiff, dark, fossiliferous clay that gradually becomes more sandy at higher levels until it assumes the appearance of typical, laminated Forest Hill sand and clay. The highest fossils observed were echinoid plates along a thin parting 23 feet above the top of the Yazoo clay. A combined thickness of 100 feet for the Red Bluff and Forest Hill was measured by barometer from the base of the Red Bluff on the Chickasawhay River to a small outlier of Marianna limestone capping a hill less than half a mile, along the strike, east of Hiwannee.

Between Hiwannee, Mississippi, and Jackson, Alabama, the Red Bluff changes markedly in lithologic character and the upper laminated sands of the Forest Hill completely disappear. In a gully alongside a country road 3½ miles southeast of Cullomberg, Washington County, Alabama, about 8½ feet of glauconitic, fossiliferous marl, containing three hard 6-10-inch limestone ledges, rests on the Yazoo clay and is overlain by 27 feet of gypsiferous plastic clay in which are several zones of calcareous and ferruginous concretions. Red Bluff fossils are present in ferruginous concretions at the very top of the section. This clay resembles the stiff, fossiliferous clay overlying the basal, glauconitic clay and marl at Hiwannee, which at that place passes upwards without a break into typical laminated Forest Hill sand. At the west pit of the cement quarry at St. Stephens Bluff, Washington County, Alabama, only 8½ feet of the upper Red Bluff dark fossiliferous clay remains. It is overlain sharply by the Mint Spring marl member of the Marianna limestone, and overlies the lower glauconitic marl and limestone member of the Red Bluff, here about 10½ feet thick.

Eight miles directly east of St. Stephens a different facies of the Red Bluff

[9] M. I. Goldman, "Basal Glauconite and Phosphate Beds," *Science*, Vol. 56, No. 1441 (1922).

is exposed in Little Stave Creek. Here the clay member has completely disappeared, and the glauconitic marl is replaced by about 15 feet of glauconitic, chalky, homogeneous limestone resembling the chimney rock of the Marianna. The ledges developed near St. Stephens are represented only by scattered concretions, and the rich fauna, containing many gastropods, found at Hiwannee and St. Stephens, is represented mainly by three pelecypod genera—*Pecten*, *Spondylus* and *Ostrea*. This limestone overlies a thin tongue of Yazoo clay, here interfingering with the Ocala limestone, and is separated from the overlying Marianna limestone by a conspicuous zone of borings. No Mint Spring marl is present, unless it is the glauconitic sand filling the borings. An undescribed and characteristic species of *Pecten* with broad, nodose ribs, which at St. Stephens occurs in the Marianna immediately above the thin sand referred to the Mint Spring marl member, occurs on Little Stave Creek immediately above the zone of borings.

This same facies of the Red Bluff is well exposed in a high bluff on Thompson Mill Creek about 100 yards downstream from the road crossing, 1½ miles southwest of Perdue Hill, Monroe County, Alabama. Here a thick section of Jackson, exposed more or less continuously down the creek to the Alabama River, is overlain by a 6-foot, 10-inch interval referred to the Red Bluff, and in turn is overlain by 40 feet of Marianna limestone. The contact between the Jackson and the Red Bluff in western Alabama suggests a period of non-deposition in moderately deep water, and, except for an accumulation of glauconite at the base and some streaks of glauconite within the Red Bluff, the lithologic break is not outstanding. Near the top of the Jackson, worm tubes, mollusks, and specimens of the coral genus *Flabellum* are present as molds and somewhat phosphatized but still in place. In, and for 1½ feet above, the basal glauconite of the Red Bluff, however, these molds are reworked and large phosphatic nodules up to 2 inches in diameter are common. Three types of crinoids have been found in the Red Bluff at this and near-by localities—one of the family Comatulidae, which embraces forms free-swimming in the adult stage and of extensive bathymetric range, and two other forms represented only by stalks, which according to Edwin Kirk are probably *Rhizocrinus* and *Pentacrinus*, genera now living in waters of 100 fathoms or more. *Dimya*, a deep-water pelecypod genus, occurs at the base of the Red Bluff at several localities south of Melvin in Choctaw County, and at Little Stave Creek in Clarke County, Alabama. The absence of basal sands characteristic of near-shore and marginal facies, together with the paleontologic evidence, suggests that the leaching of the shells and phosphatization of the molds in the upper Jackson beds took place on the ocean floor and not under subaerial conditions as is often supposed for this phenomenon. Several such zones of phosphatized molds are known in the Cretaceous of Alabama and Mississippi in sections in which it is difficult to visualize subaerial erosion. Probably the conditions that produce phosphate also leach lime and these phosphatic zones really represent special quiet deep-water conditions.

The base of the Marianna is marked on Thompson Mill Creek by a zone of short, glauconite-filled borings immediately above which a 1-foot bed of tough white limestone occurs. This limestone contains the prints of many fossils, the predominant form being a small *Mytilus*.

Practically the same section is exposed in a large gully just east of Highway 11, 1.4 miles north of Monroeville, Monroe County, Alabama, except that the interval referred to the Red Bluff is less than 5 feet thick at that place. It is possible that glauconitic limestone containing *Spondylus*, in a gully just south of the railroad cut $\frac{3}{4}$ mile north of Drewry Station, Monroe County, Alabama, may also represent the Red Bluff. If so, this is the farthest east that it has been traced. After an interval of many miles in which it appears to be cut out by the Marianna, a characteristic zone of limestone again occurs between the Marianna and the Ocala near Marianna, Florida. This zone has in the past been assigned to the Ocala. It contains, however, the misnamed, heavy, thick *Lepidocyclina fragilis* in great numbers, together with *Clypeaster*, *Spondylus*, and other genera that in other regions characterize the base of the Oligocene. The *Lepidocyclina fragilis* zone is here correlated with the Red Bluff clay.

STRATIGRAPHIC RELATIONS OF THE FOREST HILL SAND AND RED BLUFF CLAY

The concept thus far derived from this study is that the Forest Hill is the deltaic equivalent of the Red Bluff, as Cooke originally believed. Lignite deposits at the base of the Forest Hill in Hinds and Rankin counties, Mississippi, are believed to be the same in age as the basal glauconitic clay and marl of the Red Bluff at Hiwannee. More rapid deposition of sands and clays in the region of the delta accounts for the much greater thickness of the Forest Hill, whereas the more uniform and quiet marine conditions away from the delta at the east, and presumably down the dip, resulted in the comparatively thin accumulation of chalky marl. As the Forest Hill delta built up, it spread a thinning apron of clay for a short distance over previously deposited glauconitic clays, marls, and limestones on the east. The feather edge of this apron, at least, was deposited under water of sufficient depth to support a moderately rich molluscan fauna. The presence of shells in clays at different levels as far west as eastern Jasper County, Mississippi, indicates that in this region marine or at least quiet brackish-water deposition alternated with periods of more rapid deltaic or lagoonal deposition, less favorable for the support of a molluscan fauna. A specimen of the fresh-water gastropod genus *Helisoma* collected from the basal glauconitic clay at Hiwannee further indicates the proximity of non-marine areas. Locally in Mississippi the uppermost few feet of the Forest Hill sand carries a Mint Spring fauna. In Alabama the Red Bluff includes beds of two lithologic types: a basal member, composed of materials of marine origin, limestone, and glauconite, and an upper clay member, presumably the fine outwash apron from coarser sediments of the spreading, upper part of the Forest Hill delta. Westward the basal beds become less calcareous, more

clayey and sandy, and merge both laterally and vertically into typical Forest Hill sand. Eastward the basal beds become more calcareous and lighter in color, whereas the upper dark clay member thins and pinches out.

MARIANNA LIMESTONE AND INCLUDED MINT SPRING MARL MEMBER

The Marianna limestone takes its name from typical exposures along the highway just east of Marianna, Florida. Sediments included in this formation consist of soft, chalky limestone, easily sawed into chimney blocks and locally called "chimney rock"; some local, hard limestone; tough to hard ledges in the chimney rock; sandy glauconitic limestone; marl; calcareous sand; and lignitic clay. The Marianna limestone probably does not exceed 60 feet in thickness. In Mississippi and westernmost Alabama the Mint Spring marl member forms the basal part of the Marianna limestone.

A section including the total thickness of the Marianna can be measured in the two pits of the Marianna Lime Products quarry, $5\frac{1}{2}$ miles northwest of Marianna, Florida. The section in the north pit at this place, showing the lower part of the section, is as follows.

	Feet
Marianna limestone	
5. Soft, white to buff "chimney rock" containing *Lepidocyclina mantelli* (identified by T. W. Vaughan), *Clypeaster rogersi*, *Pecten poulsoni*, and scattered prints of other mollusks	40+
Lepidocyclina fragilis zone	
4. Semi-tough to hard glauconitic limestone, very glauconitic in upper 6 inches, containing abundant *Lepidocyclina fragilis* (identified by T. W. Vaughan) and *Clypeaster* aff. *C. rogersi*. Forms rimrock around deep pit in floor of quarry	$5\frac{1}{2}$
3. Softer, crumbly limestone with nodular masses and angular limestone fragments in lower part, containing abundant *Lepidocyclina fragilis* (identified by T. W. Vaughan), *Clypeaster* aff. *C. rogersi*, *Pecten anatipes*, *Spondylus dumosus*, and *Amusium ocalanum*, the last at the base and apparently reworked	$7\frac{1}{2}$
Ocala limestone	
2. Very hard limestone ledge with many *Amusium ocalanum*. No specimens of *Lepidocyclina* seen	1
1. Soft, crumbly, porous limestone with abundant *Amusium ocalanum*. No specimens of *Lepidocyclina* seen	$4\frac{1}{2}$

The south pit of the quarry goes down to the top of bed 4 of the foregoing section and shows 45 feet of "chimney rock" overlain by hard limestone ledges and dolomite referred to the Glendon limestone member of the Byram formation.

The base of the Oligocene in the foregoing section is placed at the base of bed 3, although it is not certain to what formation beds 3 and 4 should be referred. They are lithologically distinct from the Marianna limestone, and what is undoubtedly the same bed along the Chipola River was included in the Ocala limestone in a section appearing in the Florida Geological Survey's *Twentieth Annual Report*.[10] *Lepidocyclina fragilis* has heretofore been regarded as marking the top of the Ocala, but against this fossil are a *Clypeaster*, *Pecten anatipes*, and *Spondylus dumosus*, which farther west appear in Oligocene sediments above well estab-

[10] C. W. Cooke and Stuart Mossom, "Geology of Florida," *Florida Geol. Survey 20th Ann. Rept* (1929), p. 60.

lished contacts. The assumed range of *Lepidocyclina fragilis* may, therefore, have to be revised. The base of the *Lepidocyclina fragilis* zone can also be seen in an abandoned quarry just east of the highway 2 miles southeast of Campbellton, Jackson County, Florida. The *Lepidocyclina fragilis* zone is here correlated with the Red Bluff clay of Mississippi and Alabama, but, if this correlation is correct, it may deserve a new formational name because of its lithologic difference. The contact between beds 4 and 5 is not well exposed, but the difference in their lithologic character and the presence of abundant glauconite at the top of 4 suggest a break.

The "chimney rock" facies of the Marianna so well developed in the region of the type locality also occurs in western Alabama, where at St. Stephens Bluff on the Tombigbee River approximately 55 feet is exposed. In the intervening region, however, particularly in Conecuh, Escambia, and Covington counties, Alabama, a harder, coarser facies occurs. Along Murder Creek north of Castleberry, Conecuh County, soft limestone of the Marianna has been cut for chimneys but the greater part of the section is hard.

Near Brooklyn in southeastern Conecuh County, barometer readings show an interval of about 60 feet between weathered exposures of clay of the marl member of the Byram formation and the nearest exposures of the Ocala limestone. One of the most accessible places to measure this interval is along the road from a point 0.9 mile south of Brooklyn, where the Ocala is exposed in a small creek, to a point in a road cut 2 miles south of Brooklyn, where the top of the Glendon limestone member in contact with weathered brown clay of the marl member of the Byram formation can be seen.

The most complete section of limestone of Vicksburg age known in this region is the locality known as Rock House Bluff, located on the south bank of the Conecuh River, about midway of the line between Secs. 28 and 29, T. 3 N., R. 14 E., Covington County. Here 70 feet of limestone is exposed with the Eocene-Oligocene contact located 26 feet above low-water level, leaving 44 feet of tough to hard limestone referable to the Marianna, with possibly some of the Glendon limestone member of the Byram formation to be included. The *Lepidocyclina fragilis* zone, if present, was not detected at this place. All of the limestone in this section resembles the Glendon lithologically and led Cooke to believe the Marianna to be overlapped in this region. The thickness far exceeds that measured for the Glendon anywhere else, however, and it is probable that a large part, if not all, of the section is Marianna. Future study of specimens of *Lepidocyclina* collected from narrow intervals throughout the section may show whether any Glendon is present. It is possible that the "chimney rock" facies of the Marianna is present down the dip as a broad arc parallel with the present outcrops in this area.

Another section of limestone of similar facies occurs at the mouth of a cave along the east side of a large rock hill about $\frac{1}{3}$ mile north of the John Tollison farm, the exposure being somewhat south of the center of Sec. 2, T. 3 N., R. 13 E., about 3 miles southeast of Brooklyn, Conecuh County. Here 26 feet of limestone stands

in a nearly vertical cliff. A heavy, tubular-weathering ledge, probably the Glendon, stands well back from the cliff about 12 feet higher, with the slope mostly concealed. Orbitoids from this section are likewise awaiting study, but it is likely that all of this limestone is Oligocene in age.

Westward from St. Stephens, the region where the Mint Spring marl member is first recognized at the base of the formation, the limestone member diminishes in thickness, develops nodular or persistent ledges of harder limestone, and becomes more sandy and glauconitic. On the Chickasawhay River north of Waynesboro, Mississippi, it is about 30 feet thick, and on Strong River near Daniel in western Smith County, Mississippi, it does not exceed 12 feet, of which the lower 6 feet, overlying the Mint Spring, is very sandy. In the vicinity of Byram, Mississippi, only 9 feet, exclusive of the Mint Spring, can be placed in the Marianna, and of this the lower 3–5 feet forms an irregular, knotted, sandy ledge. At the section above the bridge at Vicksburg the 7 feet of beds immediately overlying the Mint Spring marl member, consisting of a lower $4\frac{1}{2}$ feet of calcareous glauconitic sand containing typical *Pecten poulsoni* and an upper $2\frac{1}{2}$ feet of glauconitic sandy limestone, is assigned to the limestone member of the Marianna. This interval is separated from the underlying Mint Spring marl member by a local diastem, discussed later, and is overlain by about 15 feet of tough to hard marlstone and interbedded softer marl referred to the Glendon member of the Byram formation.

The Mint Spring marl member, named by Cooke[11] from an exposure beneath the waterfall on Mint Spring Bayou, just below the National Cemetery at Vicksburg, Mississippi, consists mainly of fossiliferous sand, sandy marl with numerous limestone concretions, and, more rarely, concretionary ledges. Its greatest measured thickness is in the vicinity of Vicksburg, where it measures somewhat less than 25 feet. More recently Mornhinveg and Garrett,[12] in a study of the bluff at Vicksburg and its Foraminifera, included in the Mint Spring 6–8 feet of sparsely fossiliferous, lignitic clay and cross-bedded sand underlying the more fossiliferous sand. This fossiliferous fine sand or clay is commonly seen below the main fossiliferous sand in the region between the Pearl River and Vicksburg. About 4 feet of fossiliferous dark clayey sand lies between the basal glauconitic sand and conglomerate of the Mint Spring and a leaf-bearing clay in the Forest Hill at an exposure on the Chickasawhay River $1\frac{1}{4}$ miles southwest of Boyce, Wayne County, Mississippi. One species, *Turritella martinensis*, occurs in this fine sand and clay that has not been found in the Mint Spring proper, and this might justify excluding these beds from the Mint Spring. For all practical purposes such as mapping and picking contacts in bore holes they are better included in the Forest Hill sand. The Marianna limestone, and the Mint Spring marl member where present, everywhere rests with sharp contact on the underlying beds. The contact does not

[11] C. W. Cooke, *op. cit.* (1918), p. 195.

[12] A. R. Mornhinveg and J. B. Garrett, Jr., "Study of Vicksburg Group at Vicksburg, Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), pp. 1659, 1660.

everywhere indicate erosion, but, where evident, local submarine scouring rather than extensive subaerial erosion is suggested. At many places there has been no destruction of thin peat accumulations at the top of the Forest Hill deltaic deposits. At other localities, however, such as the bluff at Vicksburg as seen during the very low water of 1939, basal clays and sandy clays of the Mint Spring gently channel the underlying unfossiliferous Forest Hill sands to a depth of 2–3 feet. Similar relationship exists in the cement quarry at St. Stephens Bluff, Alabama, where pockets up to 1½ feet deep, filled with Mint Spring sand, can be seen penetrating the top of the dark Red Bluff clay. The conditions indicate that the fossiliferous Mint Spring sands were deposited rapidly and abruptly on top of the Forest Hill delta, and that the irregularity is due to bottom-scouring by currents in Mint Spring time.

Because of slight irregularities, the thickness of the Mint Spring differs from place to place. In general, the Mint Spring thins gradually from slightly less than 25 feet at Vicksburg, Mississippi, to 1½ feet at the Lone Star Cement Company's quarry at St. Stephens Bluff, Alabama, the locality farthest east to which it has been traced. Good exposures of the Mint Spring can be seen along the Big Black River, in the NE. ¼ of Sec. 8 and the NW. ¼ of Sec. 9, T. 16 N., R. 4 W.; in tributaries to the Pearl River, in Secs. 15 and 22, T. 4 N., R. 1 E., near Byram; and along the Leaf River and its tributaries in Smith County, Mississippi. The Mint Spring contains a very large molluscan fauna, largely undescribed, and the loose sand yields shells of excellent preservation. Probably the bulk of the new forms to be described in the writer's forthcoming monograph of the lower and middle Oligocene faunas will be from the Mint Spring marl. On the Chickasawhay River 1¼ miles southwest of Boyce, Wayne County, Mississippi, only about a foot of coarse sandy marl, at the base of which is a coarse clay-ball conglomerate, can be referred to the Mint Spring. This rests with sharp contact on fine dark argillaceous sand carrying *Turritella martinensis*. At St. Stephens Bluff, Alabama, the calcareous sand referred to the Mint Spring rests directly on dark Red Bluff clay, the upper 8 inches of which is somewhat leached and gypsiferous. The small molluscan fauna in the Mint Spring at St. Stephens contains genera, among them *Bathyarca*, suggestive of deposition in deeper water than that suggested by the fauna of surface exposures in Mississippi.

It is difficult at some localities to pick the exact upper boundary of the Mint Spring marl member, especially in central Mississippi, where there is a greater amount of sand in the basal part of the overlying limestone member. At Vicksburg the contact is marked by a narrow zone, well defined in fresh exposures, of worn shells and reworked phosphatic molds. Along the Pearl River south of Jackson, Mississippi, the basal part of the limestone member is commonly a more or less knotty, nodular calcareous sand, less calcareous than the top of the underlying Mint Spring marl member. Farther east, however, along Ichusa Creek, in Secs. 19 and 30, T. 2 N., R. 9 E., in eastern Smith County, the base of the limestone member is considerably more calcareous, but still contains a moderate amount

of coarse sand. On the Chickasawhay River a $1\frac{1}{2}$-foot ledge of hard sandy limestone forms the base of the limestone member. At St. Stephens Bluff three limestone ledges occur in the lower 10 feet of the limestone member, below which is about $1\frac{1}{2}$ feet of soft, argillaceous, fossiliferous sand referred to the Mint Spring. Samples taken from the base of the limestone member do not show any sand, but there is still considerably more glauconite at the base than is present higher in the formation. There is much less glauconite, however, than is found in the formation farther west.

The upper limit of the Marianna is determinable both faunally and lithologically in western Alabama and in central and eastern Mississippi, where it is overlain by the basal hard crystalline ledge of the Glendon limestone member of the Byram formation. In western Mississippi it is difficult to draw a lithologic boundary, but at the section above the Mississippi River bridge typical *Pecten poulsoni*, a Marianna species, occurs in about $4\frac{1}{2}$ feet of soft, calcareous sandy marl immediately underlying the first indurated ledge, whereas a *Pecten* with shouldered ribs identified with the Byram species occurs immediately above the first indurated ledge.

As has been stated, the lithologic similarity of the Marianna limestone and the Glendon limestone member of the Byram formation in central Alabama makes their delimitation dependent on further faunal study. Secondary dolomitization of the Glendon in the vicinity of Marianna, Florida, makes it stand in sharp contrast to the underlying chimney rock of the Marianna.

STRATIGRAPHIC RELATIONS OF MARIANNA LIMESTONE, INCLUDING MINT SPRING MARL MEMBER

The Marianna, including the Mint Spring marl member where it is present, embodies the features of a marine transgression onto a broad previously deposited delta. Near the close of Forest Hill time submergence lowered the top of the Forest Hill delta below sea-level and Mollusca living offshore invaded the new habitat, where for a short period they were buried in fine sands and clay reworked from the Forest Hill sand. Sands from new sources brought down by streams rejuvenated by the submergence soon reached the area of the present outcrop, however, and a period followed during which some 25 feet of these sands were deposited. It is perfectly clear from the field relations that the Mint Spring sands thin toward the east away from their source and pinch out in the marine limestone section in southern Alabama. They thus behave as the basal sands of the Marianna limestone and a profile from west to east simulates an updip to downdip profile.

The limestone member is regarded as a deeper-water facies following the deposition of the Mint Spring basal sands. However, although the thickness of the Mint Spring at Vicksburg is nearly half the total thickness of the Marianna of Alabama, the greater rate of deposition near the source of the sand makes it probable that all of the Mint Spring is of lowermost Marianna age. This is sup-

ported by faunal evidence, particularly by species of the genus *Pecten*, of which even the middle Marianna forms are more closely related to the Byram species than to any from the Mint Spring. Probably only the top of the Marianna of Florida is represented by the thin wedge at Vicksburg, the lag in deposition between the sand of the Mint Spring, which quickly covered the region, and the more delayed advance of the limestone facies of the transgression being represented by a diastem that widens westward across Mississippi. This diastem, which at Vicksburg may represent most of Marianna time, is characterized in that region by pebble-rounded, black phosphatic molds from an unidentified source.

BYRAM FORMATION

The Byram formation as here treated is made to include, in addition to the marl to which the name Byram was applied originally, the Glendon limestone member at the base and the Bucatunna clay member at the top. Neither the Glendon nor the Bucatunna was originally described as a member of the Byram, but the similarity of the faunas and the apparently continuous deposition throughout make it desirable to regard the beds as a single formation. Included in the Byram formation are hard, crystalline to soft, chalky limestone; sandy, glauconitic, tough marlstone and soft marl; sand; bentonitic to non-bentonitic clay, marcasitic clay, and pure bentonite.

Glendon limestone member.—Cooke, in a manuscript prepared for the Mississippi Geological Survey and still unpublished, proposed the term "Glendon limestone" to designate a member of the Marianna limestone. The essential parts of the description were first published, with due acknowledgment, by Hopkins[13] in 1917. About 18–20 feet of hard limestone ledges immediately overlying a moderately hard 9-foot bed at the top of the Marianna limestone at Glendon were referred to the Glendon limestone member. A form of weathering producing a rock filled with large tubular cavities, locally called "horsebone," was described as characteristic of the Glendon, although this tubular weathering is commonly found in the upper hard part of the Marianna originally excluded from the Glendon. The upper part of the Marianna has been included in the Glendon by some geologists on the basis that together they constitute a lithologic unit. Induration of the Marianna is not persistent, however, and may affect none or all of the formation from place to place. Such fortuitous induration therefore should hardly be construed as forming a "lithologic unit" with the Glendon.

Recent work on the section at and around Glendon has shown the Marianna to be overlain by approximately 12 feet of coarsely porous, crumbly to hard, crystalline, orbitoidal limestone with well developed but unevenly cemented ledges and interbedded less resistant zones. The hard ledges characteristically weather to "horsebone," and locally the entire interval is more evenly indurated and so weathered. At some localities, however, such as the well known exposure

[13] O. B. Hopkins, "Oil and Gas Possibilities of the Hatchetigbee Anticline, Alabama," *U. S. Geol. Survey Bull. 661* (1917), p. 300.

along the highway just north of Salt Creek between Jackson and Rockville, Clarke County, Alabama, an upper, hard 4½-foot hard zone of the Marianna is overlain by a 3-foot bed of "horsebone," which is in turn overlain by 8 feet of crumbly coquina containing abundant *Ostrea vicksburgensis*, less common *Pecten anatipes*, and a *Pecten* with shouldered ribs characteristic of the Byram. This *Pecten* has been identified in the past as *Pecten poulsoni*, but typical *Pecten poulsoni* has ribs without shoulders and probably came from the Marianna limestone at St. Stephens Bluff. *Lepidocyclina supera* (Conrad), a characteristic Byram species, makes its first appearance in this region in the basal "horsebone" ledge, whereas the indurated top of the Marianna contains *Lepidocyclina mantelli* (Morton) only. Above the coarse limestone at Glendon and constituting the remainder of the Glendon type section are at least three very hard, smooth, yellowish brown limestone ledges interbedded with soft, fossiliferous, argillaceous marl. In a gully near by are several higher narrow zones of calcareous concretions, the concretions becoming smaller and more scattered at higher intervals until the section passes into homogeneous soft clayey marl of the marl member.

In western Mississippi the crystalline "horsebone"-weathering limestone gives way to tough to hard marlstone. Ledges in this region are discontinuous and can be seen to thicken and thin considerably, and in some places to pass into unindurated beds within 100 yards or less. For this reason it is difficult to locate the base of the Glendon accurately, and where attempted it has been done mainly on the basis of the first appearance of certain species and varieties of *Pecten*, and on the first appearance of *Lepidocyclina supera*, for which the range in sections in the region of the type locality has been accurately determined. The *Pecten* with shouldered ribs characteristic of the upper marls of the Byram, and which first appears with ribs well formed in the coquina above the basal "horsebone" ledge in the Glendon, Salt Creek, and St. Stephens Bluff sections, goes through a series of developments in the limestone section at Vicksburg. Shoulders first appear on specimens in a slightly tough marl immediately above the first ledge in the section under the high-power line over the Mississippi River at Vicksburg. This is 7 feet above the zone of phosphatic molds marking the top of the Mint Spring marl member of the Marianna previously described. Passing upward the shoulders become stronger and the spaces between the ribs become more deeply channelled until after an interval of about 9 feet and continuing to the top of the bluff, about 17 feet above the top of the first ledge, the Pectens are identical with those in the stratigraphically higher soft marls of the Byram formation. The type of *Pecten* with shouldered ribs is not known in the Marianna limestone.

Geologists generally in the last decade have referred the marlstone section at Vicksburg to the Glendon. Evidence obtained by the writer indicates that the hard, crystalline limestone and open-spaced coquinas of the type Glendon section pass westward into a thicker, more uniform section of buff to cream, hard to soft, argillaceous marlstone and tough limestone. A much sharper faunal break exists between the Marianna and the Glendon in Alabama than around Vicksburg,

however, where the evolution of the Byram species is gradual. This may mean that a more continuous deposition took place in the sandy, argillaceous section on the west, whereas a short period of non-deposition followed the Marianna farther east. This finds some justification in the fact that the lower Glendon in western Alabama is practically free of sand and clay, and the coquina beds consist of shell fragments, Foraminifera, and concretionary calcareous particles with no earthy matrix between them.

The changes affecting the Glendon passing eastward from the type locality have not been worked out in detail. In south-central and southeastern Conecuh County, and in Covington County, Alabama, however, the Glendon becomes more uniformly indurated and difficult to differentiate lithologically from the Marianna, which in this region is harder and coarser than the type "chimney rock" facies. Exposures of the Glendon can be seen in this region along Murder Creek at and north of Castleberry, in road cuts, hillsides, and along the Sepulga and Conecuh rivers near Brooklyn, and along the Yellow River. Lepidocyclinas collected from all beds in these sections have been sectioned and are awaiting study by T. W. Vaughan in an attempt to fix the Marianna-Glendon boundary more accurately.

The Glendon limestone member, although present and overlying the Marianna limestone in the vicinity of Marianna, Florida, is largely altered to dolomite, an alteration affecting limestones of several formations in southern Alabama and Florida. A new road cut (1941) 0.4 mile north of the Chipola River bridge on the road from Marianna to the Marianna Caverns State Park shows a nearly complete section of the mostly altered Glendon member. This section is as follows.

	Feet	*Inches*
Byram formation		
Glendon limestone member		
9. Light bluish gray to brown bentonitic clay, largely weathered, possibly in part a concretion from weathering of bentonitic limestone or dolomite, filling caverns and solution holes in underlying dolomite, an undulating line of weathering forming the base	2+	
8. Buff, moderately tough dolomite with prints of fossils	7	
7. Buff, tough dolomite	1	6
6. Buff to gray clayey dolomite		10
5. White, hard limestone ledge where unweathered in center of cut, passing successively through zone of partly dolomitized limestone and zone of unaltered limestone pellets to buff dolomite at ends of road cut		10
4. Buff, tough dolomite with prints of *Pecten* and *Lepidocyclina* (lens of soft, unaltered cream-colored limestone, with shells preserved, on under side of unaltered part of zone above)	5	6
Marianna limestone		
3. Cream-colored, very hard limestone ledge	1	6
2. White, tough limestone with harder concretionary zones	5	
1. White, soft, homogeneous limestone	6+	

The bentonitic clay at the top of the foregoing section probably corresponds to high-grade bentonite in the Glendon limestone in Smith County, Mississippi. Bentonite also occurs between harder ledges above the Marianna limestone in the road cut along the highway just east of the Chipola River east of Marianna. As was mentioned under the Marianna, a good exposure of dolomitized ledges of the

Glendon can be seen in the rim of the south pit of the Marianna Lime Products Company's quarry, $5\frac{1}{2}$ miles northwest of Marianna.

Marl member and Bucatunna clay member of Byram formation.—In addition to the basal Glendon limestone member, the Byram formation is here made to include two higher members—the middle marl member and the upper Bucatunna clay member. The marl member, and the section from which it takes its name, is well exposed along the Pearl River at Byram, Hinds County, Mississippi. It is difficult to define this member lithologically because of its numerous facies, but it includes glauconitic sand, sandy glauconitic soft marl and tough to hard marlstone ledges, thick-bedded chalky to hard limestone, and fossiliferous, marcasitic, fine sandy clay. The Bucatunna clay member, which takes its name from exposures along Bucatunna Creek in the vicinity of Dyess Bridge in Wayne County, Mississippi, was originally described as a distinct formation in the *Guidebook* of the Eleventh Annual Field Trip of the Shreveport Geological Society. The Bucatunna clay member consists of fossiliferous, calcareous clay, dark lignitic clay, laminated fine sand and clay, laminated argillaceous fine sand with some beds of coarser sand, bentonite, and here and there a bed or streak of very fossiliferous marl at the top. Both members contain a large molluscan fauna, but unlike the marl member, which is fossiliferous throughout, the Bucatunna clay is commonly fossiliferous only at the top, and in many places is barren except for specks of lignite. Well preserved leaves occur in the upper part immediately below the Chickasawhay limestone on the east bank of the Chickasawhay River about 500 yards south of the bridge at Woodwards, Wayne County, Mississippi. Together the marl and Bucatunna clay members correspond with the *Arca lesueuri* zone, although this species is rare in the lower part of the marl member in Mississippi. In south-central Alabama and Florida, however, *Arca lesueuri* occurs in limestone low in the Byram, possibly equivalent to the Glendon farther west. A species previously reported as *Arca lesueuri* from eastern Mississippi and Alabama, in beds now placed in the Chickasawhay marl, has been described as *Arca mummi* Mansfield.[14] Possibly the early misidentification of this species, more than any other factor, was responsible for the former inclusion of the Chickasawhay beds in the Byram. The Bucatunna clay member rests conformably on the marl member and in some areas grades imperceptibly into it, except for a small area north of Waynesboro in Wayne County, Mississippi, where, apparently owing to structure, it deeply channels the beds below. This localized deep channelling is believed to be due to movement along one or several of the many faults in the area during Byram time.

At Vicksburg the marl member is believed to include some 55 feet of soft to tough, gray to green glauconitic marl, marlstone ledges, and yellow to brown oxidized sands, and, specifically, includes the beds between the cap rock on Mint Spring Bayou and the base of the laminated sand exposed on the road north of

[14] W. C. Mansfield, "Oligocene Faunas from the Lower and Upper Beds on the A. L. Parrish Farm, Washington County, Florida," *Jour. Washington Acad. Sci.*, Vol. 28, No. 3 (1938), p. 104.

the National Cemetery. The laminated sands are referred to the Bucatunna clay member. *Arca lesueuri* has been found by the writer as low as 8 feet above the cap rock of the falls in Mint Spring Bayou.

A good exposure of the contact between the marl member and the Bucatunna clay member of the Byram can be seen at the bend of the Big Black River at Mount Beulah College, 1½ miles west of Edwards in Hinds County. Here laminated dark clay with a few scattered shells along partings in the lower part overlies green to brown fossiliferous marl, and within a few feet passes upward into interlaminated fine sand and clay containing leaf fragments. Sandstone, green to gray clay, and lignite of the Catahoula cap the hill on the east.

Farther east, on the Pearl River, *Arca lesueuri* has been found 8 feet above the uppermost of the ledges referred to the Glendon, the very hard ledge seen at the north end of the exposure at Byram at very low water, and ranges throughout the overlying 45 feet of tough to hard ledges and marls. The contact of the marl member with the overlying Bucatunna clay can be seen just below a bend on the Pearl River in the SW. ¼ of Sec. 30, T. 4 N., R. 1 E., 1½ miles below the Byram bridge. A 3-foot bed of gray fossiliferous marl containing *Arca lesueuri*, exposed on Richland Creek a few feet east of the bridge in the NW. ¼ of Sec. 12, T. 4 N., R. 2 E., was determined by means of an auger hole to lie at the top of the Bucatunna clay member, which at this place is 30½ feet thick. The following section, including an auger hole, was determined at Richland Creek where it is crossed by the Brandon-Florence road.

Section on Richland Creek in NW. ¼ of Sec. 12, T. 4 N., R. 2 E., including Auger Hole in Creek Bed and continuing up Hill along Road Southward and in Gully West of Road

Exposed	*Feet*
Catahoula sandstone	
11. Light gray fine sand with coarser white sand included	2½
10. Gray clayey sand	1½
9. Dark brown lignitic streak	⅙
8. Highly weathered or concealed	9
7. Buff, thinly laminated, clayey sand grading to brown fine sandy laminated clay-shale below	27
6. Yellow to brown, moderately coarse sand with limonite partings; 1½-inch limonite layer at top	5
Byram formation	
Bucatunna clay member	
5. Gray, fossiliferous sandy marl	3
4. Dark gray to black lignitic clay with thin sand streaks near top	1½
Auger hole	
3. Same	24
2. Dark clay with shells along fine sandy partings	5
Marl member	
1. Green, fossiliferous marl	1+

The upper part of this section can also be seen in a road cut on the abandoned section of the Brandon-Jackson highway about ½ mile northwest of Brandon. Here the interval concealed at Richland Creek is shown to consist of alternating sand and clay with sand beds up to 2 feet and sandy clay beds up to 2 inches in thickness, the upper 6 inches being a lenticular tough sand ledge. The carbonace-

ous streak seen in the Richland Creek section is present here as well and is overlain by 10 feet of clayey sand. About 8 feet of the thinly laminated buff to brown clayey sand seen at Richland Creek is exposed at the base of the section.

There is clear evidence in the Richland Creek section that the unfossiliferous or lignitic laminated sand and clay shale that can be seen to overlie the marl member of the Byram at many places in Mississippi is properly a part of the Byram formation, and that it is distinct from the still higher laminated clay shale of the lower part of the Catahoula sandstone. The lower shale lies below a marl containing a typical Byram fauna, whereas the coarse sandy bed 6 of the Richland Creek section contains the large *Ostrea blanpiedi* a few miles east in Smith County. The clay-shale of bed 7 passes eastward into the brownish gray to green clay-shale of the Catahoula tongue above the Paynes Hammock sand. A hiatus between beds 5 and 6 represents the Chickasawhay limestone.

Between the Pearl River and the Leaf River the lithologic composition of the marl member changes from a series of alternating hard and soft beds to a more uniform section of fossiliferous, dark, micaceous, marcasitic, fine clayey sand, very calcareous near the base. Some zones are much more sandy and others more clayey, but it is not easily divisible into distinct beds. This is the "mineral earth" of Smith County, from which several companies are engaged in extracting a strongly acid concentrate of the decomposition products of the marcasite. When freshly obtained in auger holes from below the zone of leaching, this sand yields excellently preserved Byram mollusks, but within the zone of leaching the strong acid waters have completely dissolved the shells.

Near the Leaf River the Bucatunna clay member is cut out or overlapped by the Catahoula sandstone, here intertonguing with the Paynes Hammock sand on the east. An auger hole at the well known *Ostrea blanpiedi* locality at Keys Mill, in the SE. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 33, T. 2 N., R. 9 E., $3\frac{1}{2}$ miles south of Sylvarena, Smith County, passed downward successively through 4 feet of oyster-bearing sand, in addition to the 3 feet exposed, and 33 feet of dark, marcasitic sandy clay or clayey sand of the marl member of the Byram, containing *Arca lesueuri* throughout, and at 37 feet struck the uppermost of the hard Glendon ledges. The same ledges are exposed along West Tallahala Creek, about $\frac{1}{4}$ mile north, and along the Bay Springs-Sylvarena road just east of West Tallahala Creek. In the 33 feet of Byram penetrated, several moderately fossiliferous zones were encountered, but the lower part gradually became more and more calcareous, with some calcareous nodules, the lowest 3 feet being an almost pure foraminiferal marl with little clay included. At a bend in the Leaf River, probably in the NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 6, T. 1 N., R. 9 E., a 1-foot bed of extremely fossiliferous marl, probably one of those penetrated in the auger hole at Keys Mill, is exposed. An auger hole at this place encountered calcareous nodules at a depth of 16 feet, similar to some found elsewhere in the region just above the basal foraminiferal marl, and had to be abandoned. The fauna of this 1-foot bed is one of the largest Byram faunas known, and at least three genera of gastropods occur at this locality that have not been

found elsewhere in the Gulf Oligocene. One noteworthy fossil collected at this locality is a small species of *Archaias*, so identified by J. A. Cushman.

The section at Keys Mill is the thickest section of Byram measured in the vicinity of the Leaf River, but the total of 33 feet for the marl member is somewhat less than along the Pearl River, where about 45 feet was determined for the marl member. This locality is a downdip exposure, and as nearly as can be determined the marl member is thicker here than where it normally emerges from cover at the north. The marl member is largely cut out in western Jasper County, and the unfossiliferous upper Bucatunna clays have not been recognized. Laminated brown to gray sticky clay exposed in roadside gullies in the NW. $\frac{1}{4}$ of Sec. 31, T. 2 N., R. 10 E., has been shown by auger holes to overlie coarse, caving quicksand, and a well dug several years ago in the south center of Sec. 30 at the north encountered "very large oysters," probably in or below the quicksand, showing the clays to belong to the Catahoula tongue above the Paynes Hammock tongue.

In eastern Jasper County, however, the marl member, and probably some or all of the Bucatunna clay member, is exposed, at least in the downdip drainage. Care should be used to differentiate them from the Catahoula clays, however, which are likewise well developed. Both the Catahoula and Vicksburg are largely obscured by surficial sand that caps all the hills and drapes most of the slopes. Marl and clay of the combined marl and Bucatunna clay members can be seen just south of the center of Sec. 2, and together with the Glendon limestone member in the SE. $\frac{1}{4}$ of Sec. 5, T. 10 N., R. 10 W., southeast and southwest of Heidelberg. Dips are steep off the Heidelberg structure here, however, and clay exposed in a ditch north of a creek at the south edge of Sec. 8 of the same township was shown by an auger hole to be well up in the Catahoula. Nothing but fine sand and bright blue-green clay typical of the Catahoula and Paynes Hammock clays was encountered in a 20-foot auger hole.

The Bucatunna clay is probably present in its full thickness in southeastern Jasper County, and here the overlying Chickasawhay limestone emerges from cover. The weathered basal ledge of the Chickasawhay limestone can be seen essentially in place along a country road in the NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 26, T. 10 N., R. 9 W., about 1 mile northeast of Eucutta in Wayne County, and the underlying Bucatunna clay member of the Byram is exposed at the road-Y at the south. About $2\frac{1}{2}$ miles south, just north of a branch in the SE. $\frac{1}{4}$ of Sec. 2, T. 9 N., R. 9 W., an auger hole passed through alluvium and bright green fine sandy clay, and at 18 feet stopped on a bed of *Ostrea blanpiedi*, of the Paynes Hammock sand.

Along the Chickasawhay River northwest of Waynesboro the marl and Bucatunna members of the Byram are both present between the Glendon limestone member and the overlying Chickasawhay limestone. Under the bridge on the old Waynesboro-Laurel road at Woodwards about 3–4 feet of the Glendon extends above water level and is overlain by about 3 feet of very fossiliferous marl containing the Byram *Pecten* with shouldered ribs and *Arca lesueuri*. About 500 yards south of the bridge the base of the Chickasawhay limestone, underlain by

the Bucatunna clay, can be seen about 6 feet above low-water level. A fault undoubtedly passes between this exposure and the bridge since the Glendon was not encountered in an auger hole 22 feet below water level, much lower than it should be with the normal dip. The section at this place, including the auger hole, follows.

SECTION ABOUT 500 YARDS BELOW CHICKASAWHAY RIVER BRIDGE AT WOODWARDS, PROBABLY IN EAST CENTER OF NE. ¼ OF SEC. 3, T. 8 N., R. 7 W., WAYNE COUNTY, MISSISSIPPI

	Feet
Chickasawhay limestone	
6. Cream-colored soft to hard, irregularly indurated sandy limestone	3+
5. Cream-colored tough to hard sandy limestone, not knotty like above; contains *Echinolampus aldrichi, Pecten, Anomia, Lepidocyclina, et cetera*	5½
4. Soft blue-gray shell marl, very clayey at top, sandy below	4½
3. Irregularly indurated buff to blue-gray marl or limestone; contains *Echinolampus aldrichi, Pecten, Anomia, Turritella, Lepidocyclina, et cetera*	9½
Byram formation	
Bucatunna clay member (upper 1 foot exposed with shovel, remainder augered)	
2. Fine gray sand and interbedded gray to black fine sandy clay, becoming stiff and less sandy below 1 foot; contains well preserved leaves in upper foot	11
Marl Member	
1. Dark olive-gray to dark blue-gray fine sandy, very clayey marl; contains mollusks at different levels but abundant Foraminifera throughout; *Arca lesueuri* obtained in lower 2½ feet	11+

Several miles north of the bridge at Woodward where the preceding section was determined, there is a relatively small area in which rather active erosion took place preceding the deposition of the Bucatunna clay. Auger holes drilled by the writer have proved the existence of an intraformational disconformity with as much as 30 feet of relief on the beds below the Bucatunna, which in places cuts out both the marl member and the Glendon limestone member of the Byram, bringing the Bucatunna to rest on a part of the Marianna limestone. This area of pre-Bucatunna erosion was first pointed out by the writers of the *Guidebook* for the Eleventh Annual Field Trip of the Shreveport Geòlogical Society, but it was interpreted by them as evidence of a widespread unconformity at the base of the Bucatunna, and resulted in their referring both the Bucatunna clay and the overlying Chickasawhay limestone to the Miocene. It can be shown, however, that this profound erosion, in fact any erosion at this horizon, is extremely local, and that both east and west the Bucatunna clay menber rests conformably on the marl member of the Byram formation. Furthermore, as has been stated, the Bucatunna at other places contains a large and characteristic Byram fauna, and the laminated clays and fine sands exposed at the type locality on Bucatunna Creek at Dyess Bridge contain prints that have been identified by the writer as Byram species.

The original concept of the Bucatunna was derived largely from exposures and relationships as seen in Wayne County, Mississippi, north and northeast of Waynesboro. In this area more sand occurs in the formation than commonly exists. Several thick sandy sections were cited to illustrate the sandy phase. One section on the south bank of Limestone Creek 0.2 mile southwest (downstream) from the highway bridge over the creek shows 30 feet of sand and laminated

clayey sand, overlain by limestone boulders of the Chickasawhay, resting on a solution-pocked surface of the Glendon limestone; and another, near Limestone Church in Sec. 24, T. 9 N., R. 7 W., shows about 20 feet of finely laminated clayey sand, somewhat cross-bedded near the top and overlain by a good exposure of Chickasawhay limestone. The following section, including an auger hole at the base of the exposure, was measured at the latter locality.

SECTION NEAR LIMESTONE CHURCH ALONG COUNTRY ROAD IN NORTH CENTER OF SEC. 24, T. 9 N., R. 7 W., WAYNE COUNTY, MISSISSIPPI

Surface	*Feet*
Chickasawhay limestone	
7. Buff to gray sandy limestone and marl; contains *Echinolampus aldrichi, Pecten howei, Chione bainbridgensis, Kuphus incrassatus, et cetera*	26
Byram formation	
Bucatunna clay member	
6. Buff, somewhat cross-bedded, clayey sand with tubular structures or borings in upper part	8
5. Buff, thinly laminated clayey sand	17
Auger hole	
4. Same	2
3. Brown to buff, coarsely laminated clayey sand and clean loose sand	13
2. Yellow, clean, fluffy sand	15½
Residuum	
1. Dark, greenish gray, stiff clayey sand with 2-inch brown zone at top, dirty looking	2+

Another auger hole was drilled in a large gully in a pine thicket about 200 yards or more northwest of the above. Ledges of limestone of the Chickasawhay crop out on a low slope just back from the head of the gully. The section, including the auger hole, is as follows.

SECTION AND AUGER HOLE IN GULLY IN SE. ¼, SW. ¼ OF SEC. 13, T. 9 N., R. 7 W., WAYNE COUNTY, MISSISSIPPI

Surface	*Feet*
Chickasawhay limestone	
7. Buff weathered marl and limestone; contains *Pecten howei, Kuphus incrassatus, et cetera.*	5½
6. Concealed grassy slope to top of gully	11
Byram formation	
Bucatunna clay member	
5. Interlaminated fine sand and fine sandy clay shale; exposed in gully	22
Auger hole	
4. Same	19
3. Yellow, medium-coarse sand with two thin beds of stiff clay; coarse sand at base	6
Residuum	
2. Dark green, strongly marcasitic stiff clay with ferruginous plate at top, passing to very soft, plastic clay resembling oversoft modeling clay, dirty-looking	1
Marianna limestone	
1. Whitish, calcareous sand with fragments of *Lepidocyclina*, apparently rotten limestone, becoming very calcareous in less than a foot and passing below into soft, bluish gray limestone with well preserved *Lepidocyclina mantelli*	4+

A total of 55–60 feet is thus recorded for the Bucatunna clay at this place. As shown from material recovered from the two auger holes just a short distance apart, the amount of sand in the Bucatunna is variable, but in general the coarsest sand is in the lower part. Volcanic ash was being deposited at this time, and the clay in the Bucatunna, for the most part, is probably highly bentonitic. The very base of the Bucatunna about ½ mile upstream from the type locality at Dyess

Bridge on Bucatunna Creek, where it overlies a few feet of the marl member, is a bed of high-grade soap-like bentonite about 3 inches thick.

Throughout northeastern Wayne County the Bucatunna clay obviously fills channels and depressions on a pre-Bucatunna surface, and in general the greater the relief on that surface the thicker the Bucatunna clay. The Glendon limestone, where present, clearly exists as mesas and pinnacles buried in the Bucatunna clay. Within 1,000 feet of the two auger holes drilled near Limestone Church an exposure of rotten Glendon ledges can be seen in a road cut on Highway 45, but no Glendon was found to occur between the Chickasawhay limestone and the Marianna limestone in the auger holes. The interval for the Bucatunna here, where the marl and Glendon limestone members of the Byram and probably a part of the Marianna limestone are missing, is 55–60 feet. Near Dyess Bridge on Bucatunna Creek the Glendon limestone is present in full thickness, as well as a few feet of the overlying marl member. An auger hole at the bend in Bucatunna Creek north of the center of Sec. 6, T. 8 N., R. 5 W., passed through 3 feet of the Bucatunna clay member and 3 feet of the marl member, stopping on the Glendon limestone at 6 feet. The Bucatunna-Chickasawhay contact lies 38 feet above the top of the hole, making the thickness for the Bucatunna about 41 feet at this place. It has already been shown that near Woodwards, where the normal section is resumed, the interval of laminated lignitic sands and clay referred to the Bucatunna is only 11 feet thick, and that at least 11 feet of the marl member underlies it, the full thickness not having been determined.

The reason for such profound channeling in such a small area, near Limestone Church north of Waynesboro, is not entirely clear. This is an area of structural disturbance, however, being located near the southwest closure of the Hatchetigbee anticline and in a region known to be highly faulted. The first producing oil field to be discovered in eastern Mississippi lies just a few miles west. Because this is the only area in which the Bucatunna is known to rest disconformably on the beds below, it is probable that the channeling is intraformational and is due to uplifting or faulting during Byram time, and that some structural highs were topographic highs partly dissected before the deposition of the Bucatunna clay member.

A good exposure of the Chickasawhay-Bucatunna contact can be seen on the west slope to Bucatunna Creek in the east center of Sec. 25, T. 9 N., R. 6 W., Wayne County, Mississippi.

Near Glendon, in Clarke County, Alabama, both the marl member and the Bucatunna clay member are present in probably their original thickness for the region. Two good exposures can be seen within $\frac{1}{2}$ mile of Glendon. One is in a gully in the old Southern Railway gravel pit about $\frac{1}{4}$ mile northwest of the flag station. Here about 8 feet of very calcareous clayey marl, coarser near the base and containing calcareous concretions where weathered, overlies the Glendon limestone member, and this in turn is overlain without sharp break by 8 feet of dark, stiff, micaceous fine sandy clay referred to the Bucatunna. An auger hole back from

the zone of leaching encountered *Arca lesueuri* and other Byram mollusks throughout. A ledge of Chickasawhay limestone overlies the upper clay. Another exposure in a deep gully just south of the abandoned Jackson-Walker Springs road, about $\frac{1}{4}$ mile northwest of the gravel pit, shows about 15 feet of limestone of the Chickasawhay underlain by 4–5 feet of dark, fossiliferous Bucatunna clay. An auger hole at this locality struck a limestone ledge at 18 feet below the base of the Chickasawhay limestone. A thickness of less than 20 feet is thus indicated for the combined marl and Bucatunna clay members of the Byram in this region. Although the main zones of the western section are accounted for around Glendon, appreciable thinning of the formation toward the east is indicated. The marl member is also much more calcareous than farther west and shows a transition in this respect between the less calcareous facies to the west and the mainly limestone facies encountered in south-central Alabama and Florida.

Farther east a gully just north of the post office at Perdue Hill, Monroe County, Alabama, shows 20 feet of laminated, dark, lignitic clay of the Bucatunna, unfossiliferous except for a thin streak of marl containing *Arca lesueuri* about 1 foot from the top, underlying marl and limestone of the Chickasawhay. The total thickness of this clay has not yet been determined. On Jay Branch, near the center of Sec. 15, T. 5 N., R. 5 E., about 10 miles south-southwest of Perdue Hill, however, 15 feet of this clay is exposed and at this place contains a moderately large Byram fauna. A partial list of species from this place was published by Cooke.[15] The base of the Chickasawhay at Perdue Hill consists of $2\frac{1}{2}$ feet of gray, fossiliferous, marly sand containing a layer of phosphatic pebbles and bones at the base. Although a disconformity is suggested by the bones and pebbles, the underlying Bucatunna is not eroded. The disconformity at this horizon becomes very apparent in eastern Alabama and Georgia, however, where the Flint River formation, the equivalent of the Chickasawhay, overlaps the lower Oligocene and in places the upper and middle Eocene as well. Recent stratigraphic work in the bauxite mining regions of eastern Alabama and Georgia by the writer and other members of the Geological Survey has shown that the Flint River is resting in that area on various beds of Jackson, Claiborne, and Wilcox age.

Just below the mouth of Grab Mill Creek in Sec. 18, T. 2 N., R. 13 E., about 2 miles south of McGowan Bridge on Conecuh River at the locality sometimes known as "Weaver's Chute" (from an abandoned log chute near by), fossiliferous limestone of the Chickasawhay, largely altered to dolomite, is underlain near water level by dark, stiff clay of the Byram. This clay was determined by means of an auger hole to be $31\frac{1}{2}$ feet thick, at which depth a limestone ledge, presumably the uppermost ledge exposed at the bluff just north of McGowan Bridge, was struck. Of the $31\frac{1}{2}$ feet of material penetrated, the upper 6 feet contains more fine sand, with a bed of fine sand several inches thick at 6 feet, the next 24 feet being slick, possibly bentonitic, clay, becoming more calcareous below, and the lower

[15] C. W. Cooke, "Geology of Alabama; The Cenozoic Formations," *Geol. Survey Alabama Spec. Rept. 14* (1926), p. 290.

2 feet being a highly calcareous marly clay identical with that overlying the limestone above McGowan Bridge. Except for fragments of a thin bivalve, no mollusks were encountered in the auger hole, although Foraminifera were moderately abundant almost throughout. It is believed that all of this clay is to be referred to the Bucatunna clay member, and that the marl member is represented by the thin section of hard and soft marls seen on the upper slope to the bluff north of McGowan Bridge.

The easternmost exposure of clay of the Bucatunna member thus far recognized is on the west side of Five Runs Creek at Harts Bridge in Sec. 26, T. 2 N., R. 15 E., Covington County, Alabama. Here about 15 feet of stiff, dark clay is exposed above marls and limestones referred to the marl member. The clay exposed in the bluff is weathered, with most of its lime concentrated into pellets. Fresh material obtained from an auger hole back from the bluff showed abundant Foraminifera, the clay being dark and more plastic above and passing into lighter, very calcareous marl at the base. A *Pecten* with low, broad ribs, found elsewhere only at Jay Branch, where it occurs with *Arca lesueuri*, and in the base of the clay overlying the marlstone ledges north of McGowan Bridge, is found in the upper dark clay and also rather abundantly in a bed of buff clayey marl about 7 feet below the base of the dark clay. The interval to be included in the marl member here is not clear, as no complete sections of the lower limestone are known in the region. It appears, however, that the marl member is redeveloping both chalky and hard limestone in this region, as in western Mississippi, and is becoming less distinct from the Glendon limestone member. A hard ledge encountered in an auger hole 2 feet below the lowest marl exposed at Harts Bridge may represent the Glendon, however. Brown limestone containing *Arca lesueuri* and other Byram mollusks is exposed along the Yellow River to the southeast, probably in the SE. ¼ of Sec. 32, T. 2 N., R. 16 E.

At the Natural Bridge in the SE. ¼ of Sec. 26, T. 6 N., R. 20 W., Walton County, Florida, over 15 feet of soft chalky limestone with at least two indurated ledges, one of which forms a series of bridges, is exposed. Nearly all of the species found at Harts Bridge, including the Byram *Pecten* with large shouldered ribs, occur in this limestone, and, in addition, prints of *Arca lesueuri* are common. The Bucatunna clay member of the Byram has not been seen in this area and the limestone itself is less argillaceous than at Harts Bridge. It is possible that the lower bridge-forming ledge at Natural Bridge is properly a part of the Glendon limestone member rather than the marl member, but, if this is so, this and the limestone on the Yellow River, which is probably at the same horizon, are a lower level for the occurrence of *Arca lesueuri* than is known farther west. Road cuts south of Natural Bridge expose the Marianna limestone. The combined thickness of the Glendon limestone and the marl member of the Byram can hardly exceed 25 feet in this region.

Limestone exposed in a sink in the SE. ¼ of Sec. 3, T. 4 N., R. 17 W., 10 miles north of Ponce de Leon, Holmes County, Florida, contains a *Pecten* with very

strongly developed shoulders on the ribs that in Mississippi occurs well up in the marl member of the Byram. In texture this limestone resembles the highest limestone seen at Natural Bridge.

On the southeast in eastern Holmes, northern Washington, and western Jackson counties, Florida, is an area of pre-Chickasawhay erosion. No exposures of she Byram marls and limestones are known, and the equivalent of the Chickatawhay, here called the Suwannee limestone, rests on, or largely cuts out, the Marianna limestone.[15a] The former limestones and marls of the Byram formation, now completely dolomitized, overlie the Marianna limestone at Marianna, Florida, however, and crop out along the Chipola River for some distance south of Marianna. Cooke and Mossom indicated a broad outcrop of Byram along the Chipola River south of Marianna on the geologic map accompanying the *Twentieth Annual Report* of the Florida Geological Survey. They state,[16] however, that this interval includes everything between the Marianna limestone and the Tampa limestone and thus includes beds of Chickasawhay age as well. In the writer's opinion the Byram is exposed along the Chipola River to about a mile south of the Sink Creek bridge. At this place a ledge containing *Kuphus incrassatus*, a fossil characteristic of the Chickasawhay limestone, crosses the river. The interval between this ledge and the contact with the Tampa limestone at Richards Bend is believed to represent the Chickasawhay limestone. The base of the *Kuphus incrassatus* zone is also exposed in a sink on the A. L. Parrish farm in the SW. $\frac{1}{4}$, SE. $\frac{1}{4}$, Sec. 33, T. 3 N., R. 13 W., Washington County. The lower limestone on the Parrish farm, as well as what is apparently the same limestone at Duncan Church in Sec. 33, T. 4 N., R. 14 W., Washington County, has been considered to be middle Oligocene by both Mansfield and Cole. The most characteristic fossil at the Duncan Church locality, *Pecten duncanensis* Mansfield, has recently been found by the writer in the Byram at Natural Bridge in Walton County, and at Harts Bridge in Covington County, Alabama. This makes three localities at which this species has been found, two of which are undoubtedly Byram. *Lepidocyclina supera* also occurs at Duncan Church, along with *L. undosa* and *L. favosa*. In Mississippi *L. supera* is restricted to the Byram formation whereas *L. undosa* and *L. favosa* are restricted to the Chickasawhay limestone. At Duncan Church and several localities in the West Indies, however, these species occur together. Undoubtedly one or the other of these species is out of place, and it is not possible to say which at present. Possibly in the deepwater limestone facies *L. supera* ranges higher, and *L. undosa* and *L. favosa* range lower than in the shallower facies.

Bentonite zones in Byram formation.—Bentonite in the Vicksburg group occurs

[15a] In a recent paper by R. O. Vernon (*Florida Geol. Sur. Bull. 21*, p. 56, 1942), it is pointed out that some exposures referred to the Suwannee limestone in these counties carry faunas similar to both the marl and Glendon limestone members of the Byram and that these units might well be represented in the interval referred to the Suwannee in this region.

[16] C. W. Cooke and Stuart Mossom, *op. cit.* (1929), p. 76.

in the Mint Spring marl member of the Marianna limestone and in all three members of the Byram formation, but of these the zone in the Glendon limestone member is economically the most important. Mellen[17] in a recent report on the mineral resources of Yazoo County, Mississippi, discussed the occurrence of bentonite in the Glendon, and to him and L. C. Conant is due the credit for first accurately determining the Glendon age of the bentonite at the Attapulgus Clay Company pit near Polkville, Smith County, Mississippi. Early investigators interested primarily in the clay had reported the Smith County bentonite to be of uncertain age or possibly of Byram age. According to the *Guidebook* of the Eleventh Annual Field Trip of the Shreveport Geological Society,[18] the commercial bentonite of Smith County, particularly deposits near Lemon and Lorena, is to be correlated with bentonite and bentonitic clay in the Bucatunna clay member of the Byram formation in Wayne County, Mississippi. The opinion was furthermore expressed that the bentonite rests unconformably on and overlaps what was interpreted as the lower two-thirds of the Byram formation, and the entire Marianna limestone, and rests for approximately 2 miles on the Forest Hill sand. Work done by the writer does not support this relationship in Smith County. This does not alter the fact that the Bucatunna does rest on the Marianna limestone, or possibly lower beds in a small area in Wayne County, but merely claims that the commercial bentonite of Smith County was miscorrelated.

A fine section exposed in 1941 in the Attapulgus Clay Company pit near Polkville showed a 2-foot bed of high-grade bentonite lying approximately 1½ feet above the top of the Marianna limestone. The base of the Glendon member is an unevenly consolidated 1-foot ledge containing among other things the Byram *Pecten* with shouldered ribs and *Lepidocyclina supera*, and between it and the bentonite is a 5-inch bed of soft, chalky, glauconitic sandy marl with abundant *Pecten*, *Ostrea*, and here and there a *Spondylus*. Above the bentonite is a 12-foot section consisting of four hard yellow limestone ledges alternating with soft marl, all referable to the Glendon limestone member of the Byram formation.

The bentonite exposed in the abandoned pit of the Eastman-Gardiner Company on the property of L. J. Husband, in the NW. ¼, SE. ¼ of Sec. 19, T. 4 N., R. 8 E., about 1 mile south-southwest of Lorena, occurs between ferruginous, rotted ledges of limestone. The limestone is too much weathered to permit accurate measurement of a section, but lumps containing prints of Byram mollusks can be obtained from a layer just above the bentonite at the south edge of the pit where the overburden is undisturbed.

With the Glendon age of the commercial bentonite of Smith County once established, it would seem unnecessary to attempt to disprove that it illustrates

[17] F. F. Mellen, "Yazoo County Mineral Resources," *Mississippi Geol. Survey Bull. 39* (1940), p. 26.

[18] Urban B. Hughes, personal communication to writers of Shreveport Geological Society's *Eleventh Annual Field Trip* (1934), p. 9 (Steffey reprint).

an overlap of the Bucatunna clay onto successively older formations. It is difficult to say how much of the bentonite exposed in Smith County is actually in place, especially in regions of extensive weathering, such as that near Lemon. Flow structure and churned-up soil are common in the Smith County mines where bentonite is obviously not in place, and below Lorena slides into gullies can be seen that have bent or uprooted trees in the process of sliding. It is not at all unlikely, therefore, that bentonite can be found resting by such accident on Forest Hill surfaces. In parts of the pit near Polkville sliding or squeezing has taken place, and bentonite from the original 2-foot bed between ledges of the Glendon limestone, mixed with detritus, rests on a Marianna slope, filling depressions in it as much as 7 feet deep.

Bentonite and bentonitic clay occur in both the marl member and the Bucatunna clay member of the Byram formation, and the waxy clays, found locally in the Chickasawhay limestone and more commonly in the Paynes Hammock sand and the Catahoula sandstone, may also be bentonitic. No bentonite has yet been reported from Wayne County at the same horizon as that at Polkville or Lorena, however, but a 3-inch bed of apparently equal quality occurs at the base of the Bucatunna clay member of the Byram formation where it is exposed on Bucatunna Creek about ½ mile above Dyess Bridge. An auger hole at Dyess Bridge penetrated it at 3 feet below water level. At higher horizons the clay becomes more sandy and develops sand laminae up to 2 inches in thickness. Except for this one area, all of the bentonite in the Bucatunna appears to be sifted and transported, and was either redistributed from purer marine accumulations or was derived from land-laid ash or bentonite deposits. Specks of lignite are almost universally present.

As was discussed in connection with the Glendon limestone member, the bentonite occurring several feet above the top of the Marianna limestone at Marianna, Florida, probably corresponds with the deposits in Smith County, Mississippi.

Relationships of members of Byram formation.—The final stage in the advance of the chalky limestone facies of the Marianna was followed by uniform limestone deposition from Vicksburg to Florida. In western Mississippi a series of alternating hard and soft, sandy, glauconitic marls and limestone was deposited, while in eastern Mississippi and western Alabama the very hard, coarse to smooth crystalline, orbitoidal limestone of the typical Glendon sequence was laid down. From south-central Alabama to western Florida, however, the facies changes to more homogeneous limestone. The Glendon probably represents the most widespread thoroughly marine phase of Gulf Oligocene deposition. Some sand was included in the Glendon in the vicinity of the present Mississippi River, but for the most part crystalline or only slightly argillaceous limestone was deposited. The occurrence of a bed of bentonite of such quality as that in Smith County attests the absence of detritus-bearing currents. Although separable both faunally and lithologically, there is no evidence of disconformity between the Marianna and the

Glendon, although a nearly complete cessation of clastic sedimentation appears to have taken place, at least locally, at the beginning of Glendon time.

Following the period of limestone deposition the seas once again became shallow, and sands and clays were laid down in increased abundance. Sandy, glauconitic limestone or marlstone continued to be deposited in western Mississippi for awhile, but from central Mississippi to western Alabama calcareous marl and fine sandy, micaceous clay, partly bentonitic, followed closely the deposition of the Glendon limestone. From south-central Alabama southeastward into Florida the facies changes from marl to chalky limestone to hard limestone. Near the close of Byram time a blanket of fine to medium sand and clay was deposited from the Mississippi River to Florida. This is called the Bucatunna clay member of the Byram formation. The Bucatunna is largely unfossiliferous lignitic sand and clay, but in southern Alabama it becomes calcareous and somewhat fossiliferous. In Mississippi and western Alabama a thin marl bed or marly zone occurs at the top at several places. Faulting in at least one area during Bryam time caused the marl and Glendon members to be deeply eroded prior to the deposition of the Bucatunna clay member.

CHICKASAWHAY LIMESTONE, PAYNES HAMMOCK SAND, AND CATAHOULA SANDSTONE

Because of the close relationship of the Tampa limestone, the Catahoula sandstone, the beds here named the Paynes Hammock sand, the Chickasawhay limestone (as here restricted), the Flint River formation, and the Suwannee limestone and because of the correlations both correct and incorrect that have been made between them in the past, it is necessary that they be discussed together.

In 1918 limestones and marls here referred to the Chickasawhay limestone and the Paynes Hammock sand were included in the Byram marl by Cooke[19] in his classification of the Gulf Oligocene. In 1926 Cooke[20] included in the Byram of Alabama many localities and sections now referred to the Chickasawhay limestone.

In 1934 in the *Guidebook* for the Eleventh Annual Field Trip of the Shreveport Geological Society, published anonymously except for certain paleontologic chapters, a new classification for the Gulf Coast Oligocene was proposed, in which the names Bucatunna and Chickasawhay first appeared. The Bucatunna clay and the Chickasawhay, which was divided into an upper and a lower member, were included with the Catahoula sandstone in a "Catahoula group" and referred to the Miocene. Two contributors to the *Guidebook*, M. A. Hanna and D. W. Gravell, dissented from this arrangement, however, and grouped the Bucatunna and lower part of the Chickasawhay together in a "Limestone Creek group" which they regarded as distinct from the Vicksburg group but still Oligocene in age. They

[19] C. W. Cooke, *op. cit.* (1918), p. 196.

[20] ——— (1926), pp. 287–93.

united the upper member of the Chickasawhay with the Catahoula to make a Catahoula group of Miocene age, although apparently not on paleontologic evidence, as no species from the upper member were cited.

In response to these proposals Cooke[21] in 1935 accepted the terms Bucatunna clay and Chickasawhay marl but regarded both units as members of the Byram marl of the Vicksburg group. He declined to accept the division of the Chickasawhay into two members, however. In 1938 Hazzard and Blanpied[22] accepted the Limestone Creek group of Hanna and Gravell, including the Bucatunna formation and the Chickasawhay formation, as distinct from the Catahoula, but maintained a Miocene age for the Limestone Creek group. At the same time, however, they stressed a correlation upon which apparently everyone agrees: that the "lower Chickasawhay" beds are the equivalent of the Flint River formation of Alabama, Georgia, and Florida and of the Suwannee limestone of Florida.

In 1939 Cooke[23] in a discussion of the Oligocene-Miocene boundary pointed out that whether the Chickasawhay is Oligocene or Miocene is immaterial, so far as local correlation is concerned, and depends on: first, a decision as to the position of the boundary in Europe, a question far from settled; and second, accurate correlation of American and European deposits. In a correlation chart in the same paper, Cooke accepted the Chickasawhay marl as a formation distinct from the Byram, but still included it in the Vicksburg group. He still declined to accept the division of the Chickasawhay into two members. The Bucatunna he continued to regard as a member of the Byram.

According to the classification currently accepted by the United States Geological Survey, the Tampa limestone is correlated with the Aquitanian of Europe and is placed at the base of the Miocene, following the most commonly accepted of the European viewpoints. If the Chicaksawhay (as here restricted) is of the same age as the Flint River formation and the Suwannee limestone, it must be Oligocene in age, since these two formations definitely underlie the Tampa limestone. The foregoing correlation, based mainly on marine Mollusca, finds some verification in the vertebrate fossils. A part of the vertebral column of a manatee collected by the writer from the Chickasawhay limestone at Choctaw Bluff on the Alabama River, Clarke County, Alabama, has been identified by Remington Kellogg, of the United States National Museum, as an Oligocene manatee, most closely related to forms in the upper Oligocene of France and not closely related to Miocene species.

The arguments put forth by the various contributors to the *Guidebook* to show that the Oligocene-Miocene boundary should be placed lower than heretofore

[21] C. W. Cooke, *op. cit.* (1935), pp. 1165–70.

[22] Roy T. Hazzard and B. W. Blanpied, "Stratigraphic Relations of the Limestone Creek Group, Wayne County, Mississippi" (abstract), *Amer. Assoc. Petrol. Geol. Twenty-Third Annual Meeting Program* (March 16, 1938), p. 11.

[23] C. W. Cooke, "Boundary between Oligocene and Miocene," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23 (1939), pp. 1560, 1561.

accepted on the Gulf Coastal Plain have been based on local, or supposed regional, disconformities, mainly the supposed disconformity at the base of the Bucatunna clay. Even if such a disconformity did exist, and certainly a great regional disconformity or onstep at the base of the Flint River formation, the equivalent of the Chickasawhay in eastern Alabama and Georgia, does exist, it would have no bearing on the problem. As was stated in the introduction, the major time divisions of the Tertiary are based on the marine molluscan faunas in the European section, and formational or group divisions based on lithology or disconformities in other parts of the world could hardly be expected to coincide with these intervals. The Tampa limestone is correlated with the Aquitanian of Europe, and European geologists are not in agreement as to whether the Aquitanian is Oligocene or Miocene. The main problem in this country, therefore, is not whether the Chickasawhay and its equivalents should be placed in the Miocene, but whether the overlying Tampa limestone and at least a part of the Catahoula sandstone are not really Oligocene, and whether the base of the Miocene more nearly corresponds with the base of the Hawthorne formation of Peninsular Florida and Georgia and the Chipola formation of western Florida. The delimitation and naming of the formations above the Catahoula, as well as the upper limit of the Catahoula, in Mississippi is still largely open to question, and it is quite possible that the base of the Chipola formation is equivalent to some horizon within the Catahoula formation of Mississippi.

Chickasawhay limestone and Paynes Hammock sand.—The Chickasawhay limestone, as previously stated, was named in the *Guidebook* for the Eleventh Annual Field Trip of the Shreveport Geological Society for exposures along the Chickasawhay River near Waynesboro, Mississippi. Beds exposed in the region were divided into the "Lower Chickasawhay member" and the "Upper Chickasawhay member" of the Catahoula group, a system of nomenclature not acceptable to the Geological Survey. The Geological Survey later accepted the name "Chickasawhay marl" for the entire interval. Only the "Lower Chickasawhay member" of the *Guidebook* is here called the Chickasawhay limestone. The "Upper Chickasawhay member" is renamed the Paynes Hammock sand, from an exposure along the Jackson fault at Paynes Hammock, on Tombigbee River, in the SW. ¼ of Sec. 16, T. 5 N., R. 2 E., Clarke County, Alabama. Near Waynesboro the Chickasawhay is predominantly limestone with some soft marl, some hard calcareous sandstone, and some dark, probably bentonitic, clay near the top. The best exposures of the formation are to be seen along the Chickasawhay River beginning about 500 yards below the bridge on the old Waynesboro-Laurel road at Woodwards and continuing intermittently for more than a mile south, where its contact with the Paynes Hammock sand can be seen both above and below the new bridge. One good exposure can be seen on the east side of the river about midway between the two bridges, where 22 feet of limestone occurs in a vertical cliff. The texture of the limestone ranges from soft chalky limestone of the "chimney rock"

type through crumbly, fossiliferous limestone to very hard, dense limestone. The thickness estimated from exposures along the river is between 30 and 35 feet.

The writers of the *Guidebook* correlated the "Lower Chickasawhay member" with the Suwannee limestone and the "Upper Chickasawhay member" with the Tampa limestone. The main problems involved in these correlations are: whether or not, as claimed by the writers of the *Guidebook*, the "Upper Chickasawhay member" is Tampa in age; whether the thin fossiliferous interval referred by them to the "Upper Chickasawhay member" represents the entire Tampa limestone or whether at least part of the overlying Catahoula is Tampa in age as well; or whether the "Upper Chickasawhay member" as delimited by them is still Suwannee in age and the base of beds referred by them to the Catahoula is the same horizon as the base of the Tampa. Two important factors are involved in this correlation—one the relationship of the faunas of the "Lower" and "Upper" Chickasawhay and the other the actual tracing of the recognizable units from Mississippi to Florida.

The last, and to date the most important, contribution to the correlation of the Chickasawhay limestone is the description of the molluscan fauna by the late W. C. Mansfield.[24] Mansfield's stratigraphic notes were never compiled, but such comments as appear with the discussion of species show that he was clearly of the opinion that the fauna from localities designated "Lower Chickasawhay" by the writers of the *Guidebook* is similar to that of the Flint River formation and the Suwannee limestone and is upper Oligocene in age. A table of selected species from the "Lower Chickasawhay" prepared for Mansfield's paper by its editor shows an overwhelming preponderance of species comparable with Byram species over those comparable with Tampa species. Of the forms found specifically identical with those of other formations, 2 are identical with Byram species, 12 with Flint River species, and none with Tampa species. A complete list would probably show a somewhat higher percentage of forms closely related to Tampa species, but these are for the most part elements of the fauna thus far unknown in the Flint River and Suwannee formations. Such species as *Fusiturricula waynesboroensis* Mansfield, the closest known relative and obviously the forerunner of *Fusiturricula lapenotieri* (Dall), fall into this category. The genus *Scobinella*, found in the "Lower" Chickasawhay, is not known in undoubted Miocene formations in North America, although it occurs in the Miocene of the West Indies and South America. The species from the Chickasawhay is much more like Vicksburg species than the latter, however. Of the species of the "Upper Chickasawhay" beds, some give strong evidence of Tampa age. A large gastropod apparently restricted to the "Upper Chickasawhay" has been identified by Mansfield as *Ampullina* (*Ampullinopsis*) *amphora* (Heilprin). This species, according to Mansfield, has not been found to occur below the Tampa limestone in Florida. A simi-

[24] W. C. Mansfield, "Mollusks of the Chickasawhay Marl," *Jour. Paleon.*, Vol. 14 (1940), pp. 171–225.

lar but smaller *Ampullina* does occur in the "Lower Chickasawhay," where it is found in association with *Kuphus incrassatus* Gabb, a large marl-boring teredid. This same *Ampullina* has recently been found by the writer in the Suwannee limestone in a sink east of the famous Falling Water sink south of Chipley, Florida, where it is likewise associated with *Kuphus incrassatus.* Collections from the highest beds heretofore referred to the Chickasawhay of Alabama, made by the writer since the publication of Mansfield's paper, contain some species that seem very definitely to correlate these beds with the Tampa. One of these is a large *Cyrena*, probably *Cyrena floridana* (Dall) of the Tampa limestone. A large *Crassatella* is also closely related to one of the Tampa species and is unlike any known from the Suwannee and the restricted Chickasawhay limestones.

There appears to be, therefore, a definite change of fauna within the beds formerly included in the Chickasawhay marl from one of Suwannee aspect in the lower part to one of Tampa aspect in the upper part. If the base of the Tampa is taken to be the base of the Miocene, the Oligocene-Miocene boundary would, therefore, lie between the former divisions of the Chickasawhay. Eustatic changes of importance undoubtedly took place in the Gulf Coastal region just before Chickasawhay time as evidenced by a break at the base of the Chickasawhay and by the fact that the equivalent Flint River formation overlaps a considerable thickness of beds below it in eastern Alabama and Georgia. As discussed later, however, sections both east and west of Wayne County, Mississippi, suggest that at least an equal disconformity exists at the base of the Tampa limestone and the Paynes Hammock sand, and that the Paynes Hammock and Catahoula overlap beds below them on the west.

In order to trace the lithologic units from Wayne County, Mississippi, both to Florida and to the west, it is first necessary to define these units and the contacts between them in Wayne County. The contact between the "Upper" and "Lower" Chickasawhay was said by the writers of the *Guidebook* to be exposed on the west bank of the Chickasawhay River about 200 yards south of the bridge on the new Waynesboro-Laurel road. The section at this place is as follows.

SECTION ON WEST BANK OF CHICKASAWHAY RIVER ABOUT 200 YARDS SOUTH OF BRIDGE ON NEW WAYNESBORO-LAUREL ROAD

	Feet	*Inches*
Paynes Hammock sand		
17. Hard, blue-gray limestone ledge, weathering buff		2
16. Coarse, unsorted, greenish gray, calcareous sand or marl with large glauconite grains and abundance of dark brown mineral weathered soft, probably garnet.	1	
15. Olive-green zone of waxy shale and shale flakes, probably bentonite		2
14. Olive-green bentonitic (?) fine sand or silt with large white sand grains; contains *Ostrea blanpiedi*, a smaller oyster, and fragments of other mollusks	1	6
13. Greenish gray to buff, calcareous, argillaceous fine sand with coarser white sand grains, non-glauconitic; contains prints of a moderately large inflated lucinoid and other mollusks	1	
12. Greenish medium sand with both entire and broken shells of *Ostrea blanpiedi*, small, coarsely sculptured *Pecten*, lignite fragments, bone fragments, and pebbles at base		4–6
Chickasawhay limestone		
11. Gray fine sandy shale with carbonized sticks and stems—seen only at highest point of bed below and elsewhere eroded		2–0
10. Gray-green fine sand with soft shells of mollusks, bentonitic (?)		8–0

	Feet	Inche.
9. Greenish gray, hard, fine sandy marlstone ledge with borings of softer sand that weather out; contains medium-sized *Venericardia* in abundance		6
8. Greenish gray calcareous, bentonitic (?), glauconitic, medium-grained sand with soft shells, about 1½ feet in center tough and indurated; contains echinoid *Echinolampus aldrichi*, *Anomia*, and other mollusks	3	
7. Greenish gray, waxy, bentonitic (?) clay with small fragile mollusks, zone of borings in upper 4–6 inches filled with sand of bed above	2+	
6. Concealed	6	6
5. Greenish gray, tough, glauconitic, sandy marl with prints of shells	1	6
4. Bluish green, soft, calcareous sandy marl; contains *Chlamys howei* Mansfield	1	
3. Gray, tough marlstone ledge; contains *Kuphus incrassatus*, *Chione bainbridgensis*, *Echinolampus aldrichi*, and other fossils		6
2. Soft greenish gray calcareous, glauconitic sandy marl with soft shells	1	6
1. Hard calcareous sandstone, weathering to "horsebone"; contains *Kuphus incrassatus* and other mollusks	2+	

It will be noted that the contact between the Chickasawhay limestone and the Paynes Hammock sand is located somewhat higher than the line selected by the writers of the *Guidebook* for the boundary between the "Lower and Upper Chickasawhay members." The contact was placed by them near the base of the concealed interval No. 6.

About 200 feet above the bridge the following section showing the beds above the fossiliferous part of the section was made. This includes beds exposed in the river bluff, a large borrow-pit back from the bluff north of the road, and an auger hole in the borrow-pit.

SECTION JUST UPSTREAM FROM BRIDGE ON NEW WAYNESBORO-LAUREL ROAD

	Feet	Inches
Catahoula sandstone		
17. White to brown, medium-textured soft sand, slightly cross-bedded, with some ferruginous induration	20+	
Catahoula sandstone (basal member)		
16. Gray to buff, plastic to somewhat blocky clay with moderately abundant white quartz grains at top	1–3	
15. Blue-green to gray fine argillaceous sand, with irregularly bedded gray silty clay and some shaly zones; flattened marcasite nodules in upper part	24	
14. Stiff gray to buff clay, mostly concealed	9	
13. Buff-gray soft sand, slightly argillaceous, with some coarse white sand grains and some buff clay flakes	1	6
12. Brown to black sand, probably stained by ground water		2–3
Paynes Hammock sand		
11. Buff, tough to hard sandstone ledge, with prints of mollusks		6–10
10. Greenish blue to gray soft sandy marl, with medium-sized white sand grains, leached above, very calcareous below; contains abundant echinoid spines	3	
9. Buff-gray, tough to hard sandy limestone or marlstone, tough in upper part, hard below; contains prints of mollusks	2	6
8. Brownish gray, unsorted sand with brown mineral, probably garnet; contains *Ostrea blanpiedi* and fragments of other mollusks		6
7. Olive-green flaky clay (bentonite?) with pockets of sandy marl		6
6. Soft, bluish green, medium-textured, micaceous, calcareous, argillaceous sand; contains large *Ostrea blanpiedi*, small oyster, and fragments of other soft shells	2	
5. Bluish gray to buff, tough marlstone ledge, with medium-coarse white sand grains; contains prints of mollusks	1+	
Chickasawhay limestone		
4. Concealed	8	6
3. Gray, silty, bentonitic (?) clay	1+	
2. Interbedded soft to tough marl; contains *Chlamys howei* and *Kuphus incrassatus* (corresponds with beds 2 to 5 below bridge)	5	
1. Hard calcareous sandstone ledge weathering to "horsebone"	1+	

The lithologic change between beds 11 and 12 in the foregoing section is at first glance much more important than the break between beds 11 and 12 in the section south of the bridge, for not only does it separate beds of different color, but fossiliferous from non-fossiliferous beds as well. The break, largely because of weathering, is more apparent than real, however, for other sections, such as that along Patton Creek southeast of Waynesboro, show that the upper sands and clays are actually highly calcareous like the fossil beds below, and that leaching and induration can also alter them to a hard fine-grained quartzitic sandstone that rings under the hammer. On close examination the upper sands of the Chickasawhay limestone are much more uniform in grain size. The beds above referred to the Paynes Hammock sand, however, contain more unsorted material and are especially characterized by large clear quartz grains in a fine silty clay or fine calcareous silt matrix. Large grains of a brown mineral, probably garnet, are found in the coarser, unsorted sands.

In the vicinity of Jackson, Alabama, sections are known that show a considerable interval of sand above the basal limestones of the Chickasawhay, the highest part of which, at least, contains Tampa fossils. The base of the Chickasawhay is a soft, cream-colored limestone with some tougher zones, resting directly on the Bucatunna clay member of the Byram formation. No complete sections of the limestone are known, but at least 15 feet is exposed in gullies near Glendon. Above the limestone is a thick section of greenish clayey sand, quicksand, coarse carbonaceous (?) sand, calcareous sandy marl, and impure sandy limestone. Exposures of the top and bottom of the sandy interval are unknown, and attempts to auger through it were frustrated by quicksand. The two known exposures have been preserved by being downthrust along the Jackson fault, and owing to its incompetent nature it could hardly have resisted deep weathering and erosion except where so protected.

On Little Stave Creek, Clarke County, Alabama, just west of the northeast corner of Sec. 30, T. 7 N., R. 2 E., a 42-foot section was measured, of which about 14 feet is exposed and 28 feet were augered, the lower part being very dark and dirty-looking, probably stained by ground water. The exposed part of this section contains a bed of the large tube ***Kuphus incrassatus*** Gabb, a fossil not found in the "Upper Chickasawhay" in Wayne County, Mississippi. The beds are dipping moderately steeply upstream at this place, and below a concealed interval of about 150 yards downstream the soft basal limestone of the Chickasawhay containing *Chlamys howei* is exposed in a low bluff.

The other exposure is along a branch entering the Tombigbee River at Paynes Hammock, Alabama, from which the Paynes Hammock sand takes its name, in the SW. $\frac{1}{4}$ of Sec. 16, T. 5 N., R. 2 E. Here about 13 feet of greenish sand containing one indurated limestone ledge can be seen. This sand is faulted against the Marianna limestone in a small side fault to the main Jackson fault. The section given by Cooke[25] in his report on the "Geology of the Coastal Plain of Alabama"

[25] C. W. Cooke, *op. cit.* (1926), p. 288.

is on the upthrown side of the fault. An auger hole at the lowest exposed part of the greenish sand had to be abandoned at 25 feet because of a second bed of quicksand after 12 feet at the top had been cased off. Material obtained from the lower part of the hole resembled the highest sand exposed in the Little Stave Creek section. Over half of the fossils collected from the sand and limestone ledge at Paynes Hammock are unique, but among them is an *Ampullina*, apparently the same as that identified as *Ampullina* (*Ampullinopsis*) *amphora* (Heilprin) occurring in the "Upper Chickasawhay" in Wayne County, Mississippi. A large *Cyrena*, probably *Cyrena floridana* (Dall), from the Tampa, occurs just above the limestone ledge. A large but poorly preserved *Pyrazasinus* is also in the collection. It is probably the same species as one occurring at Wileys Landing on the Flint River in Georgia. Another fossil from this locality is *Turritella tarponensis* Mansfield, a very characteristic turritella described by Mansfield from the Tampa limestone at Tarpon Springs, Florida. A small *Arca* also compares with one from Tarpon Springs. The thickness of this sand, although not accurately determined, greatly exceeds the thickness of the "Upper Chickasawhay" of Wayne County, Mississippi. *Ampullina* (*Ampullinopsis*) *amphora* and *Kuphus incrassatus*, which in Wayne County occur within a few feet of one another, are separated in the section near Jackson, Alabama, by many feet of unfossiliferous sand. The Oligocene-Miocene contact, although not exposed, is believed to be located somewhere within this unfossiliferous interval.

The contact between the Tampa and Suwannee limestones, with which units the Jackson, Alabama, and Wayne County, Mississippi, sections are to be correlated, is well exposed at Falling Water Sink in the NW. $\frac{1}{4}$ of Sec. 27, T. 4 N., R. 13 W., Washington County, Florida. Here tough clayey sand with a bed of rounded, hard limestone pebbles at the base and containing a small fauna of characteristic Tampa mollusks, including *Pecten crocus* Cooke, rests on a very hard, solution-pocked ledge of the Suwannee limestone, which continues, less indurated, some 60 feet to the bottom of the sink. This break is important both faunally and lithologically, and at first, and even second, glance it appears to be greater than the break between the "Upper" and "Lower" Chickasawhay on the Chickasawhay River. The break is undoubtedly emphasized here, however, by the differential east-west facies change of the two formations. To the west the Paynes Hammock sand rests on upper sand and sandy marl of the Chickasawhay, but the Chickasawhay passes into solid limestone much more rapidly than does the Paynes Hammock. In western Florida the Suwannee is a soft to hard limestone throughout, but the Tampa, although here called limestone, is far from typical Tampa and is still largely a sand. These basal Tampa sands can be seen to have scoured the top of the Suwannee limestone in Falling Water Sink. So far as the writer knows, this is the only exposure of this contact in Florida.

An excellent exposure of soft limestone, apparently the Falling Water sink facies of the Suwannee limestone, can be seen in the large quarry of the Florala Lime Products Company at Adams Crossroads, on the lower Florala-Hacoda road

in southeastern Covington County, Alabama. Orbitoids and other large Foraminifera occur at this place in abundance.

No good exposures that show the complete upward transition from the fossiliferous Paynes Hammock sand to the non-fossiliferous beds lithologically typical of the Catahoula are known between Wayne County, Mississippi, and Florida. Throughout southern Alabama, however, dark to light gray clays and some quartzitic sandstones are found at greater to lesser intervals above the Chickasawhay marl. Limestone of the Chickasawhay is exposed in a cut of the Alabama, Tennessee and Northern Railway about 1.3 miles north of Millry, Washington County, Alabama, but the next cut about $\frac{1}{4}$ mile south consists of laminated dark clay and sand. A few unidentifiable prints of a pelecypod were found in the clay. Gray sand, clay, and hard quartzitic sandstone, typical of materials found in the Catahoula to the west, can be seen at the bridge over Murder Creek at Kirkland, Escambia County, Alabama. About a mile north of Kirkland, probably in Sec 23, T. 3 N., R. 10 E., a ledge of tough calcareous marl containing *Echinolampus aldrichi*, a fossil characteristic of the "Lower Chickasawhay," crosses the creek.

The farthest west that the Paynes Hammock sand is recognized is the locality at Keys Mill, Smith County, Mississippi, where it passes both laterally and vertically into the Catahoula. At this place, 7 feet of medium-coarse sand containing many individuals of the large oyster *Ostrea blanpiedi* Howe overlies marcasitic clayey marl of the Byram formation. No Bucatunna clay or Chickasawhay limestone is present below the oyster bed. The contact at the base of the oyster bed has not been seen, but the abrupt lithologic change suggests an important break. *Ostrea blanpiedi* has been found in Wayne County only in the beds here referred to the Paynes Hammock sand.

Two interpretations are possible at this place: either the section overlying the Byram is the Paynes Hammock-Catahoula sequence of the Chickasawhay River section and has here cut out or overlapped the Chickasawhay limestone and the Bucatunna clay member of the Byram; or *Ostrea blanpiedi* does not hold its place in the Paynes Hammock sand, but here occurs in beds equivalent to the basal part of the Chickasawhay limestone, with both the higher beds of the Chickasawhay and the Paynes Hammock sand not differentiated from the Catahoula sandstone in this region. Both the lithologic features and the regional picture indicate that the first alternative is correct, however. The sand containing *Ostrea blanpiedi* at Keys Mill is nearly identical in appearance and texture with the Paynes Hammock sand containing this species along the Chickasawhay River and with that obtained in an auger hole in the northwestern part of Wayne County, where *Ostrea blanpiedi* was also encountered. The basal Chickasawhay limestone, on the other hand, is a smooth, cream-colored limestone from south-central Alabama to the westernmost exposures known in northwestern Wayne and southeastern Jasper counties, and there is no reason to suppose that it changes to a coarse sand within the next 20 miles. Neither the oyster bed nor any other fossiliferous material resembling the Paynes Hammock can be seen at the base of the Catahoula

near Raleigh, in Smith County, and it is the writer's opinion that the Paynes Hammock has passed both laterally and vertically into the lower part of the Catahoula sandstone.

If this interpretation of transition of the Paynes Hammock into the Catahoula is correct, the relationship between the Catahoula and the beds to the west is that of a simple overlap. The Paynes Hammock, which is equivalent to the basal Catahoula, overlaps the Chickasawhay limestone in central Mississippi. From here to the Mississipppi River the Catahoula sandstone rests variously on the Bucatunna clay and the marl members of the Byram, and some unreleased data on core holes drilled by an oil company in western Mississippi suggest that locally it rests on much lower beds.

The writer has made only a brief reconnaissance of the known Vicksburg deposits of Louisiana, but there seems to be clear evidence that the Catahoula overlaps the Vicksburg section between the Mississippi and Sabine rivers. Near Rosefield in Catahoula Parish, Louisiana, the Catahoula rests on marl of the Byram formation; southwest of Derry, Natchitoches Parish, the Catahoula appears to rest on the Mint Spring marl member of the Marianna limestone; and along Highway 171 between Hornbeck and Anacoco, Vernon Parish, the Catahoula rests on the Forest Hill sand.

Catahoula sandstone and younger deposits.—Because of the complex relationships between the Chickasawhay limestone, the Paynes Hammock sand, and the Catahoula sandstone, most of the features of the Catahoula have already been described.

As was indicated in the section at the new bridge west of Waynesboro, the equivalent of the Tampa limestone of Florida in this region consists of a lower fossiliferous zone called the Paynes Hammock sand and an upper zone referred to the Catahoula sandstone. Eastward the entire interval becomes the fossiliferous Tampa limestone, and westward the Paynes Hammock sand merges both laterally and vertically with the lower beds of the Catahoula sandstone. The Paynes Hammock sand and the Catahoula sandstone thus duplicate the relationship between the Red Bluff clay and the Forest Hill sand.

Westward the Catahoula, although mainly non-fossiliferous, does have some marine tongues within it. Marine fossils have been found in stiff clay exposed in a railroad cut about a mile west of Mendenhall, Simpson County, Mississippi, in beds that are probably well up in the Catahoula. A bed of sand in the lower part of the Catahoula, seen in a road cut along the Brandon-Florence road in the south center of the SW. $\frac{1}{4}$ of Sec. 23, T. 14 N., R. 1 E., Rankin County, Mississippi, contains the fossil *Halymenites*, believed to be a boring made by some animal, perhaps a shrimp-like crustacean, and a reliable indicator of shallow-marine deposition.

Above the basal fine sands and clays of the Catahoula in Wayne County, Mississippi, is a thick section of beds of quite different lithologic composition. The lower part of these beds is very well exposed at the top of the measured section at the new bridge west of Waynesboro. Nearly 100 feet of beds higher in the section

can be seen in the hill just south of Waynesboro on the Leakesville road. The lower part of the section consists of some 70 to 100 feet of loose sand and ferruginous sandstone, above which is a zone of gray sandy clay, commonly red-splotched, of variable thickness. This is overlain by sand and gravel, probably river terrace. The upper laminated white sands and clay are well exposed in a ditch near the top of the hill and in a large gully just over the top of the hill west of the road. Sand, marl, and marlstone of the Paynes Hammock are exposed in the bank of the river west of the bridge 25–30 feet below the lowest sand exposed.

The assignment of this loose sand and clay above the more typical Catahoula clays is still conjectural. It has been referred to both the Catahoula sandstone and the "Citronelle formation," the latter a term so loosely used and inclusive of so many things that it has lost definite meaning. The sand is at much too low an elevation to project into the sand and gravel beds seen overlying the Catahoula sandstone south of Ellisville in Jones County, near Mendenhall in Simpson County, and near Crystal Springs in Copiah County, which are probably referable to the Willis formation of Doering.[26] As yet incomplete work suggests that a significant break is developing in eastern Mississippi within beds referred to the Catahoula, and that the upper part, consisting mainly of loose sand with clay lenses, passes east into the Hawthorne formation of the Alum Bluff group, and that only the lower part of the Catahoula sandstone is Tampa in age.

[26] John Doering, "Post-Fleming Surface Formations of Coastal Southeast Texas and South Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), p. 660.

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ANAHUAC FORMATION[1]

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ABSTRACT

Because of the need for a name for the "Middle Oligocene" beds of Texas, the name Anahuac has been designated as the name for the formation including the *Discorbis*, the *Heterostegina*, and the *Marginulina* zones. The paper includes a history of the "Middle Oligocene" with mention of differences of opinion as to the age, a lithologic and paleontologic description, an electrical log of the type well, and one cross section showing the position of the Anahuac.

INTRODUCTION

There is a national movement to create new formations in the subsurface where needed. In the Tertiary of the Gulf Coast of Texas, the subsurface formation to which the name Anahuac is now being given has since 1925 been designated as the "Middle Oligocene" formation or, by its three paleontological zones, the *Discorbis*, the *Heterostegina*, and the *Marginulina*.

At the request of the post-Cretaceous sub-committee of the geologic names and correlations committee of the American Association of Petroleum Geologists, a local correlation committee was named by the Houston Geological Society. The members of this committee were Carl B. Richardson, chairman, Lon D. Cartwright, Jr., Shirly Mason, F. W. Rolshausen, and C. F. Sanders. Because of the need for a name for the "Middle Oligocene" formation embracing the three paleontological zones already mentioned, the local committee was consulted by the post-Cretaceous sub-committee in selecting a new formation name. The name suggested by the local committee was "Lockridge shale," from the Lockridge field, Brazoria County, Texas. However, the chairman and the Houston members of the post-Cretaceous sub-committee did not favor this name. After careful consideration of all the facts and details necessary in the selection of a type locality, these members of the post-Cretaceous sub-committee decided that the geologic section of the Anahuac oil field, Chambers County, Texas, better fulfills the requirements for the type locality of this particular formation. The Houston members of the post-Cretaceous sub-committee were Thomas L. Bailey, Marcus A. Hanna, and Wayne V. Jones, with W. Armstrong Price of Corpus Christi, chairman. The writer was asked by the chairman of the post-Cretaceous sub-committee to describe the Anahuac formation.

The writer is indebted to Morgan J. Davis, chief geologist, and to the directors of the Humble Oil and Refining Company for permission to publish this paper; to the various oil companies for their permission to use the electrical logs of their wells; to Cecil Gill for his painstaking drafting of the cross section; to Marcus A. Hanna for making prints of fossils described by him and Donald W. Gravell.

[1] Manuscript received, March 10, 1944.

[2] Humble Oil and Refining Company.

Recent field work with W. C. Blackburn coördinated the field work previously done by him and other Humble Oil and Refining Company geologists in various counties. The writer is grateful to him for his hearty coöperation on this surface work.

While this paper was in process of being written, J. Brian Eby[3] used the term "Anahuac Wedge" in his report on the oil and gas fields of Jackson County, Texas. As he referred indirectly to this paper, it may not be necessary to change the type locality to some field in Jackson County.

TYPE LOCALITY

The type locality of the Anahuac formation is the Anahuac oil field, 5 miles east of the town of Anahuac, the county seat of Chambers County, Texas. The field is accessible by a paved highway from Beaumont, Texas. Anahuac is a very old county seat and the name is shown on all state maps, postal maps, and the United States Geological Survey base map of Texas. The discovery well of the field, the Humble Oil and Refining Company's Middleton No. 1, is the well selected for the description of the Anahuac formation, which is present in the well from 5,890 feet to 6,984 feet. The well is in the southeast corner of the H. & T. C. C. Railroad Survey, Sec. 58. This test was completed, March 15, 1935, at the total depth of 7,088 feet, producing 775 barrels daily through $\frac{3}{8}$-inch choke from 7,040 feet to 7,081 feet in the Frio sand. The elevation of the well is 29 feet above sea-level.

HISTORY

Fossils characteristic of the Anahuac formation were first found in the early part of 1921 in a well drilled by the Humble Oil and Refining Company in the Goose Creek oil field in Harris County, Texas. Soon after, similar fossils were found in wells drilled by the Humble Oil and Refining Company at West Columbia field and then at Damon Mound field in Brazoria County.

At Goose Creek these fossils occurred in bluish gray calcareous shaly clays grading into dark greenish gray calcareous sandy clays. These marine beds occurred below the non-marine sands and sandy clays of the Fleming. As oil was found in sands later known to be in the *Marginulina* zone, the entire Anahuac section was not penetrated for a number of years. It was then learned that beneath the Anahuac at Goose Creek were the non-marine sands of the Frio which become marine downdip.

The key fossil of this fossiliferous shale section was *Heterostegina* sp. The writer had a limited paleontological library. In order to identify the Foraminifera, as well as the age of this marine formation, the fossils were sent to J. A. Cushman. The *Heterostegina* was identified by Cushman as *Heterostegina antillea*,

[3] J. Brian Eby, "Oil and Gas Fields of Jackson County, Texas," *Oil Weekly* (September 27, 1943), pp. 20–26.

which he regarded as the characteristic fossil of the Antigua formation of the West Indies, and as being Oligocene in age. T. Wayland Vaughan[4] stated: "The Antigua formation must, in my opinion, be the type of the American Middle Oligocene." On this evidence, this marine formation in the Texas Gulf Coast was called "the Middle Oligocene."

In 1925, Esther Richards Applin, Hedwig T. Kniker, and the writer published the first description of the Texas middle Oligocene.[5] By this time the "Middle Oligocene" formation had been divided into three paleontological zones, the uppermost designated the *Discorbis* zone, the middle the *Heterostegina* zone, the basal the *Marginulina* zone. The fauna of each zone was listed. No precise work had been done on the foraminiferal identifications, and the Foraminifera were considered by many paleontological authorities as a doubtful means of correlation. The writers depended principally on Cushman's contributions on the recent material and the Vicksburg of Mississippi for their identifications of the "Middle Oligocene" species. Their species were compared with published forms and many new species were recognized to which manuscript names were given. At this time the lithologic character of the three paleontological zones in different fields was recorded.

During the Anahuac period, coral reefs developed around some of the salt domes, for example, West Columbia, Damon Mound, Boling, and Barber's Hill. Here the facies of the middle faunal zone, the *Heterostegina* zone, is a coral-reef limestone. This limestone phase of the *Heterostegina* zone was noted in the original paper of 1925. In 1926, the writer called attention to these coral reefs in a paper on the "Coral Reefs in the Oligocene of Texas."[6] In 1929, D. P. Carlton[7] in his paper on the West Columbia salt dome, Texas, referred to this limestone as the "Columbia lime."

Increased drilling furnished additional information. Deeper wells yielded a great number of new species. There was a need for proper description and publication of the fossils and coördination of the work done by the different laboratories. Donald W. Gravell and Marcus A. Hanna published the larger forms; J. B. Garrett and A. H. Ellis, Jr., J. A. Cushman and Alva C. Ellisor published a number of the smaller species. The complete fauna is yet to be described. As more workers entered the field and the Anahuac formation became of more and more economic importance, there began a difference of opinion as to the age of this

[4] T. Wayland Vaughan, "Contributions to the Geology and Paleontology of the Canal Zone, Panama and Geologically Related Areas in Central America and the West Indies," *U. S. Nat. Mus. Bull. 103* (1919), p. 203.

[5] Esther Richards Applin, Alva C. Ellisor, and Hedwig T. Kniker, "Subsurface Stratigraphy of the Coastal Plain of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 1 (1925), pp. 79–122.

[6] Alva C. Ellisor, "Coral Reefs in the Oligocene," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 10 (October, 1926).

[7] D. P. Carlton, "West Columbia Salt Dome and Oil Field, Brazoria County, Texas," *Structure of Typical American Oil Fields*, Vol. 2, Amer. Assoc. Petrol. Geol. (1929), pp. 451–69.

unit. Two schools of thought came into existence, one holding that the age is Miocene, the other that the age is Oligocene.

In 1933, Henry V. Howe[8] in his paper on the "Tertiary Stratigraphy of Louisiana," stated:

> The writer is therefore suggesting the strong probability that the *Heterostegina* zone and perhaps the *Discorbis* and *Marginulina* zones also should be correlated with the Chattahoochee formation, or Tampa limestone as the "down-dip" or seaward facies of the Catahoula. However, until the micro-faunas of the type Tampa, and of these zones are properly described and figured, the correlation cannot be other than suggestions.

In the same paper, Howe placed the Catahoula formation, the Tampa limestone, and the present Anahuac in the Miocene. In recent conversations with the writer, Howe said he correlates the Anahuac with the upper Tampa or younger, which in turn is correlated with the upper Chickasawhay, regarded by him as Miocene in age. He also regards the lower Chickasawhay as Suwannee equivalent and to be Oligocene in age. He considers the Anahuac and both members of the Chickasawhay to be the marine equivalents of the surface non-marine Catahoula.

In 1937, Donald W. Gravell and Marcus A. Hanna[9] described, from the "Middle Oligocene" beds of Texas and Louisiana, a number of larger Foraminifera, two of which were *Heterostegina texana* and *Heterostegina israelskyi*. They pointed out that the Antiguan species, *Heterostegina antilla*, was not present in Texas. They also described two species of *Lepidocyclina* from the Anahuac, *Lepidocyclina colei* and *Lepidocyclina texana*. On the presence of the *Lepidocyclina*, they placed the age as upper Oligocene. In this paper they discussed the difference of opinion about the age of these beds, also the difference of opinion among the European geologists about the contact of the European Oligocene and Miocene beds. In conclusion they stated:

> If the terms Miocene and Oligocene must be used in the Gulf Coast, we believe it more logical to consider the *Heterostegina* zone and associated beds, the Chickasawhay and associated beds, and the Vicksburg and associated beds as Oligocene, rather than part Oligocene and part Miocene. At the same time we welcome any additional information that will aid in definite establishment of this contact. Until sufficient opposing evidence is presented, we believe it best to follow established usage and consider the *Heterostegina* zone as a part of the Oligocene.

In the Florida section Cole,[10] in 1941, placed the *Heterostegina* zone in the Oligocene and the Tampa in the Miocene.

In a correlation chart compiled recently by C. Wythe Cooke, Julia Gardner,

[8] Henry V. Howe, "Review of Tertiary Stratigraphy of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 6 (1933), pp. 613–55; also in *Gulf Coast Oil Fields* (1936), pp. 383–424.

[9] Donald W. Gravell and Marcus A. Hanna, "The *Lepidocyclina texana* Horizon in the *Heterostegina* Zone, Upper Oligocene, of Texas and Louisiana," *Jour. Paleon.*, Vol. 11, No. 6 (1937), pp. 517–29.

[10] W. Storrs Cole, "Stratigraphic and Paleontologic Studies of Wells in Florida," *Florida Geol. Survey Bull. 19* (1941), pp. 9–13.

and Wendell P. Woodring[11] the Tampa limestone and the Catahoula sandstone are correlated with the Aquitanian which is regarded by them to be lower Miocene in age. The Chickasawhay marl is correlated with the Suwannee limestone which is regarded as upper Oligocene; the Frio clay of Texas is correlated with the Vicksburg limestone of Louisiana and the Vicksburg group of Mississippi and Alabama. The age of the Frio and correlatives is regarded as middle Oligocene.

The difference of opinion about the Miocene-Oligocene contact on the Gulf Coast is due to the questionable position of this contact in Europe and to the questionable correlation of the Anahuac with the Tampa of Florida. The terms Miocene and Oligocene have their origin in Europe where the opinion is divided about the point of contact. Most American authorities accept the correlation of the Tampa with the Aquitanian. However, the European geologists do not agree about the age of the Aquitanian. It is not practicable to review here all that has been published on the age of the Aquitanian stage, whether uppermost Oligocene or lowermost Miocene. Schenck[12] after spending a year or so studying the Oligocene problem in Europe arrived at the conclusion that the Aquitanian stage of Europe should be placed in the Oligocene. In his paper he cited many modern European geologists who hold the same opinion and stated that "More may do so when they realize that the Miocene has a designated type locality."

It is the writer's opinion that the Anahuac of Texas is older than the Tampa of Florida and that it is Oligocene in age since the Tampa is regarded as being either lowermost Miocene or upper Oligocene.

The writer agrees with the views expressed by Gravell and Hanna[13] in their discussion of the *Heterostegina* zone where they state that

> it is unfortunate that a diversity of opinion exists regarding which beds are Miocene and which are Oligocene since these two terms have been used extensively by the petroleum industry. Many published records pertaining to production and reserves are based on the Oligocene-Miocene contact being above the *Heterostegina* zone and not at the top of the Vicksburg. These terms will continue in use since they are established in the records of the petroleum industry. A shifting of this contact as one or the other school of thought dictates can cause only confusion. The problem itself cannot be settled until the problem is settled in Europe. and until the Gulf Coast section can be precisely correlated with that of Europe. Even when precise correlation seems established with one group of fossils, it may not be with another group of fossils. It is believed the goal will not be reached for many years to come.

It may be said in conclusion that the purpose of this paper is to introduce into

[11] C. Wythe Cooke, Julia Gardner, and Wendell P. Woodring, "Correlation of the Cenozoic Formations of the Atlantic and Gulf Coastal Plain and the Caribbean region, " *Bull. Geol. Soc. America*, Vol. 54, No. 11 (1943), pp. 1713–24.

[12] Hubert G. Schenck, "What Is the Vaqueros Formation of California and Is It Oligocene?" *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 4 (1935), pp. 521–36.

[13] Donald W. Gravell and Marcus Hanna, "Subsurface Tertiary Zones of Correlation through Mississippi, Alabama, and Florida," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 8 (1938), pp. 984–1013.

the published record a name for the formation in Texas which has for long been called the "Middle Oligocene" formation, not to settle any controversy about the age of these beds.

STRATIGRAPHIC POSITION

In Texas the Anahuac formation in the subsurface extends across the coastal area from the Sabine River to the Rio Grande, but does not occur on the surface. It lies between the basal sands of the Fleming above and the subsurface Frio below.

FLEMING FORMATION

Dumble,[14] in 1918, described some outcrops of Corrigan (Catahoula) clays and sandstones around Moscow in Polk County. He said that a "porcellaneous cemented Corrigan sandstone" 15 feet thick capped the top of the Moscow hill. J. W. Leggett of Livingston, Texas, found typical Fleming calcareous clays with an abundance of calcareous nodules and reworked Cretaceous material north of these "Catahoula-like" beds which he decided were inliers of Catahoula in the Fleming clays. Prior to 1928 he told E. D. Phillips of the Humble Oil and Refining Company about these "inliers" of Catahoula. Later he pointed out additional "inliers" of Catahoula in the Fleming in Polk, Tyler, and San Jacinto counties to Frith C. Owen, W. C. Blackburn, and Perry Olcott of the Humble Oil and Refining Company.

Core tests by the Humble Oil and Refining Company on these so-called "Catahoula inliers" drilled through formations lithologically like Catahoula into typical blue and green calcareous clays and sands of the Fleming containing reworked Cretaceous material, thus proving that these green non-calcareous clays, coarse sands, and conglomerates were indigenous to the Fleming. After additional field work, Leggett found numerous localities in Polk and San Jacinto counties where typical calcareous Fleming clays with an abundance of reworked Cretaceous material occur stratigraphically below these Catahoula-like outcrops and concluded that in the lower part of the Fleming there was a zone of calcareous clays below a zone of non-calcareous clays, sands, and conglomerates resembling the Catahoula.

Later Blackburn mapped in detail these two zones in the lower part of the Fleming across Polk and San Jacinto counties. Perry Olcott mapped them across Tyler County. The lower of the two zones consists of dark blue, green, and gray calcareous clays with reworked Cretaceous material and an abundance of calcareous nodules and lenses of sands. This lower zone is predominantly calcareous, but non-calcareous green clays with no reworked Cretaceous material are interlaminated with the calcareous clays. These clays weather into deep black soil. This zone ranges from 150 to 200 feet in thickness.

[14] E. T. Dumble, "The Geology of East Texas," *Univ. Texas Bull. 1869* (1918), pp. 205–06.

The upper zone consists of non-calcareous green clays, sands, conglomerates, and mudstones, and is estimated to be 150–175 feet thick. The coarse sands and indurated conglomerates of this zone closely resemble the "rice sands" of the Catahoula. One outstanding locality pointed out by Leggett is an old "wash hole" on Kelly Springs Branch 3½ miles southeast of Moscow in the northeast corner of Section 8 in the M. J. Taylor Survey in Polk County. In this area a complete section of this zone can be seen. This zone has mottled red weathering resembling the Lafayette. Above this non-calcareous zone is another zone of calcareous clays. The succeeding beds of the Fleming consist of alternate zones of sands and clays some of which are non-calcareous.

The type locality of the Fleming as described by Kennedy[15] is near the former town of Fleming, later called Hampton, in Tyler County, and is located on the basal calcareous zone previously described. Kennedy, after describing the clays in detail, stated that the clays were

> overlaid by and associated with a series of gray sands, which are mostly coarse grained, sometimes massive and in localities cross-bedded and stratified. The typical exposure seen at Fleming shows them to be gray stratified sand containing fossil palm in great quantities with numerous quartz, jasper and other pebbles, and to have at that locality a thickness of twenty feet.

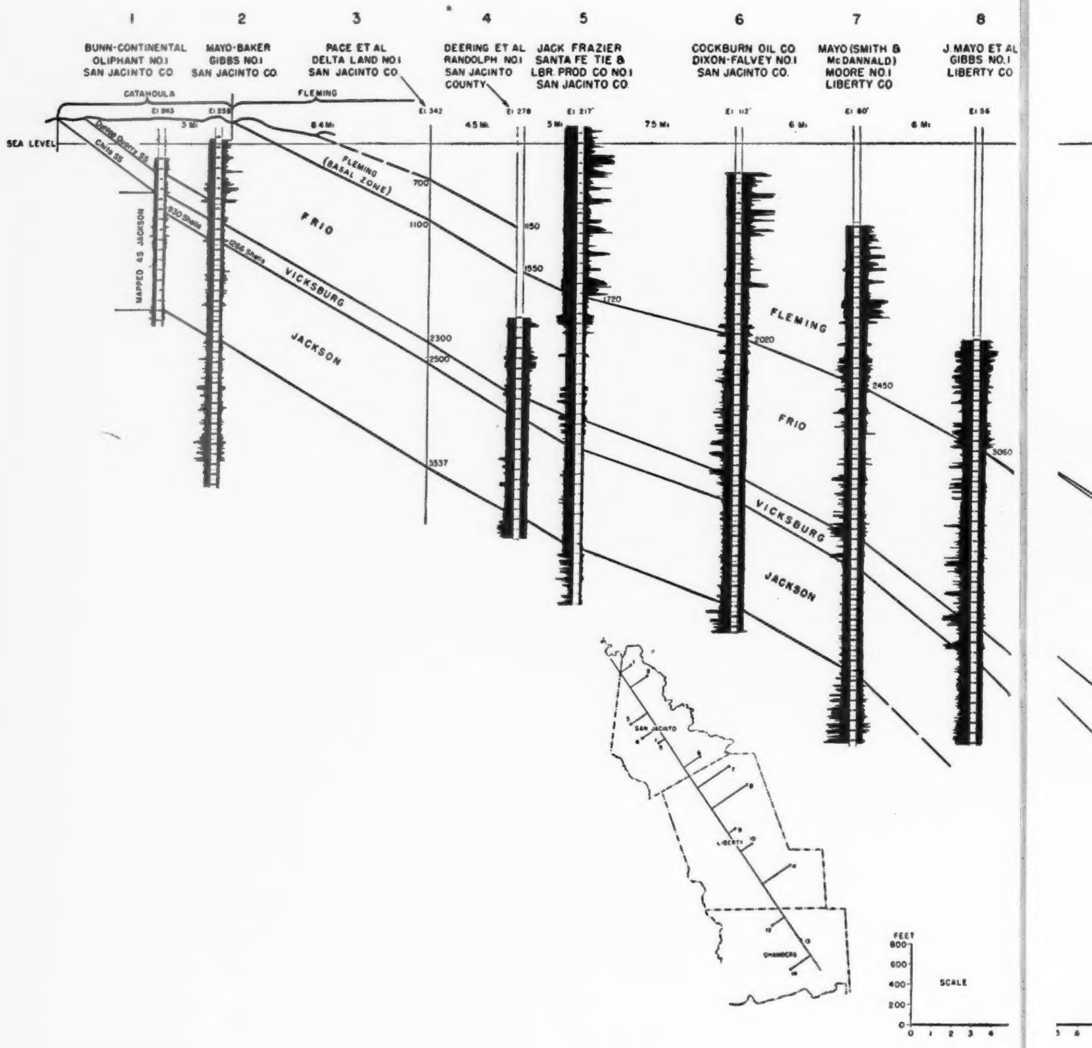
These sands form the basal part of the non-calcareous zone described in the foregoing paragraph.

This basal zone of calcareous clays at the type locality in Tyler County can be traced across Polk, San Jacinto, and Walker counties into the lower Oakville as mapped in Grimes, Washington, Fayette, and Lavaca counties by Humble Oil and Refining Company geologists and by Coleman Renick.[16] The sand member overlying these clays at the type locality is traceable westward from Tyler County across Polk, San Jacinto, and Walker counties into the cuesta-forming sandstone in Grimes, Washington, Fayette, and Lavaca counties, which Renick has called the Moulton sandstone at the base of his middle Oakville. In eastern Grimes County a marked change occurs. These non-calcareous clayey sands, fine to coarse sands, and conglomerates which contain no reworked Cretaceous material and which weather into mottled red resembling the Lafayette, become the typical Oakville gray sands, highly calcareous and with an abundance of reworked Cretaceous material.

As non-calcareous beds resembling the Catahoula do occur in the Fleming on the surface, so in the subsurface above the Anahuac are non-calcareous beds in the Fleming which for many years have been called the Catahoula. The surface Catahoula and the subsurface Frio are believed to be equivalents.

[15] William Kennedy, "A Section from Terrell, Kaufman County, to Sabine Pass on the Gulf of Mexico," *Texas Geol. Survey 3rd Ann. Rept.* (1892), pp. 62–63.

[16] B. Coleman Renick, "The Jackson Group and the Catahoula and Oakville Formations in a Part of the Texas Gulf Coastal Plain," *Univ. Texas Bull. 3619* (1936), pp. 76–84.



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BUNN-CONTINENTAL OLIPHANT NO.1 SAN JACINTO CO.
MAYO-BAKER GIBBS NO.1 SAN JACINTO CO.
PACE ET AL DELTA LAND NO.1 SAN JACINTO CO.
DEERING ET AL RANDOLPH NO.1 SAN JACINTO COUNTY
JACK FRAZIER SANTA FE TIE & LBR. PROD. CO NO.1 SAN JACINTO CO.
COCKBURN OIL CO DIXON-FALVEY NO.1 SAN JACINTO CO.
MAYO (SMITH & McDANNALD) MOORE NO.1 LIBERTY CO
J. MAYO ET AL GIBBS NO.1 LIBERTY CO
CATAHOULA
FLEMING
SEA LEVEL
FLEMING (BASAL ZONE)
FRIO
VICKSBURG
JACKSON
MAPPED AS JACKSON
FLEMING
FRIO
VICKSBURG
JACKSON
700
1100
1150
1550
1720
2020
2300
2500
2450
3060
3537
SAN JACINTO
LIBERTY
CHAMBERS
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800
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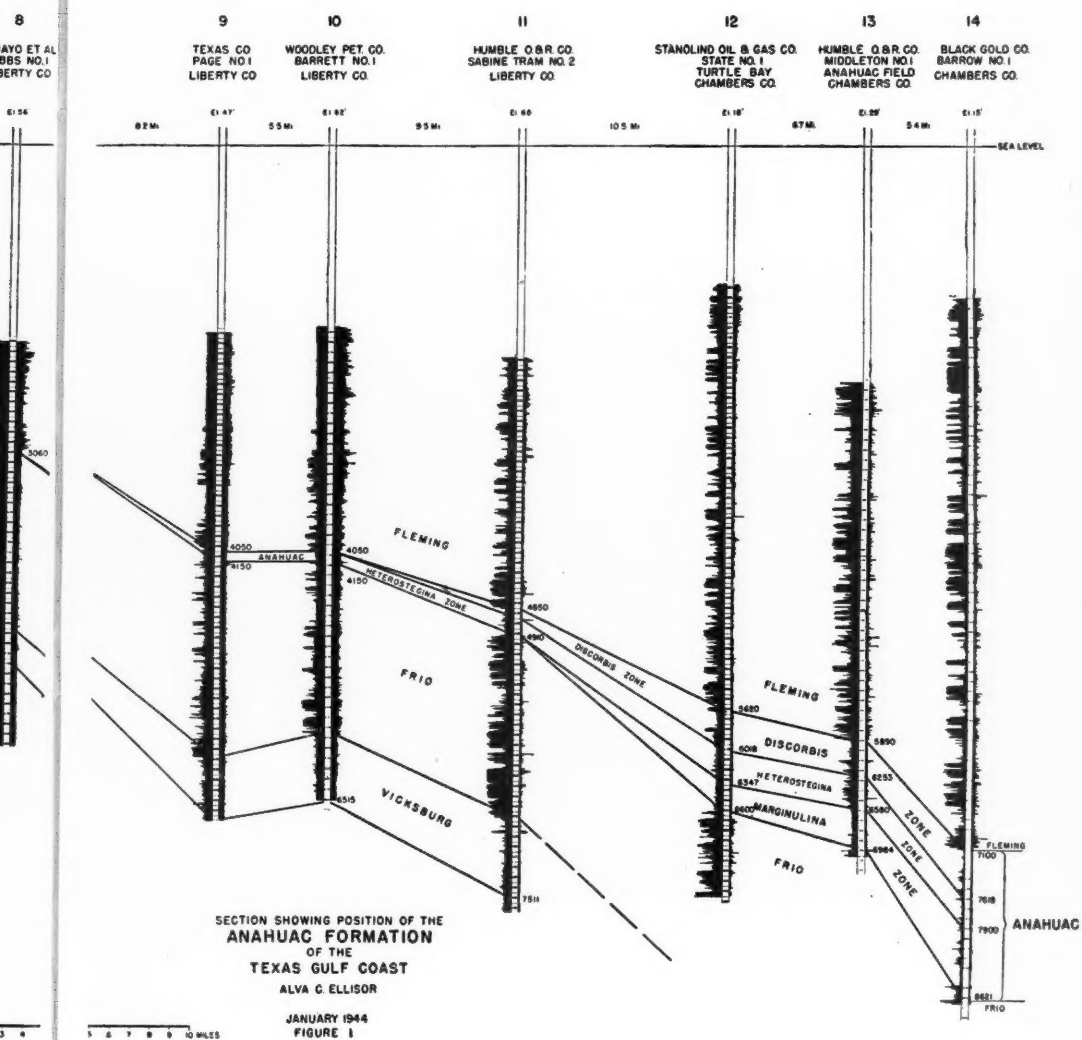


SECTION SHOWING POSITION OF THE
ANAHUAC FORMATION
OF THE
TEXAS GULF COAST
ALVA C. ELLISOR

JANUARY 1944
FIGURE 1

CROSS SECTION

A cross section (Fig. 1), drawn through Anahuac field from the Black Gold Company's Barrow No. 1 in southern Chambers County, Texas, to the surface in San Jacinto County, shows the position of the Anahuac. The contacts of the three paleontological zones are indicated. All contacts made in this cross section are based on lithological and paleontological studies of well samples as well as surface samples.

The sand zone immediately above the Anahuac has been referred to in Humble Oil and Refining Company reports as the "basal Miocene" sand. In the Humble Oil and Refining Company's Middleton No. 1 and the Black Gold Company's Barrow No. 1 the section above the Anahuac was cored. The beds are greenish gray calcareous sandy clays and sands, containing reworked Cretaceous material, *Rotalia beccarii*, *Textularia* sp., *Elphidium* sp., ostracods, and oyster fragments. In wells, as on the surface, reworked Cretaceous material characterizes the Fleming clays and sands and is not typical of the Catahoula formation. Downdip commonly a few species of the *Discorbis* zone are found in lignitic shale lenses in the Fleming above the "basal Miocene" sand. Reworked Cretaceous material and abundant *Rotalia beccarii* are also present. Because of these *Discorbis* species there is some difficulty in determining the top of the Anahuac. The writer prefers to place the top of the Anahuac at the base of reworked Cretaceous material. In the area between the Humble Oil and Refining Company's Sabine Tram No. 2 and Mayo, Smith, and McDannald's Moore No. 1 this basal sand member of the Fleming contains a few megascopic fossils in addition to the oysters, among which is recognized a *Divaricella* sp. Farther updip this fossiliferous sand grades into non-marine gray "pepper-and-salt" sand which consists of coarse to medium-sized, angular, subangular, and rounded fragments of clear quartz, black, green, brown, and yellow cherts, jaspers, and feldspars. Reworked Cretaceous material is here and there present. On the surface a vari-colored sand lithologically like this sand is commonly found at the base of the Fleming.

In the area from the Woodley Petroleum Company's Barrett No. 1 to the Black Gold Company's Barrow No. 1, the Fleming is ordinarily calcareous. However, updip from Barrett No. 1 green non-calcareous beds are interlaminated with the calcareous beds. Volcanic glass and green bentonitic clays are present in places. These beds grade updip to the surface into the two zones of the Fleming described previously, the basal one being the clays of the type locality. The non-calcareous beds in the subsurface above the Anahuac are indigenous to the Fleming as they are on the surface, not the Catahoula as believed in the past.

The Anahuac overlies the Frio. From J. Mayo *et al.* Gibbs No. 1 to the surface the basal "pepper-and-salt" sand of the Fleming, which is commonly called the "basal Miocene" sand, overlies the yellow-green non-calcareous tuffaceous clays of the subsurface Frio.

Downdip from the Humble Oil and Refining Company's Sabine Tram No. 2,

Liberty County, the Frio is fossiliferous. The Foraminifera are Oligocene in age. The Frio in this well is essentially sand with lenses of shale. A few pelecypods are found in the top of the section, a few Foraminifera in the shale lenses. Downdip, fossiliferous lignitic shale lenses replace some of the sands. The Humble Oil and Refining Company's Middleton No. 1 penetrates the Frio for a short distance, as does the Black Gold Company's Barrow No. 1. Other wells in the Anahuac field show that the Frio in this area is highly fossiliferous.

Updip from Sabine Tram No. 2 the Frio becomes less fossiliferous. In the Woodley Petroleum Company's Barrett No. 1 and in The Texas Company's Page No. 1 the Anahuac overlies non-marine green clays with lenses of coarse quartz sand. Beneath these green clays and sands are brown lignitic shales containing a few pelecypods and arenaceous Foraminifera. Beds of "rice" sands occur in the lower section of these lignitic shales. It is by means of a "rice" sand at the base of the Frio that the contact with the Vicksburg is determined where the fossils of the Vicksburg are absent. In many fossiliferous sections the fossils are not found at the top of the Vicksburg for various reasons; therefore, the base of the last "rice" sand is used to determine the top of the Vicksburg.

The "rice" sands in the basal part of the subsurface Frio are the downdip equivalent of the series of "rice" sands in the basal part of the Catahoula on the surface which have been designated the Chita sandstone and the Dunlap Quarry sandstone by Renick.[17]

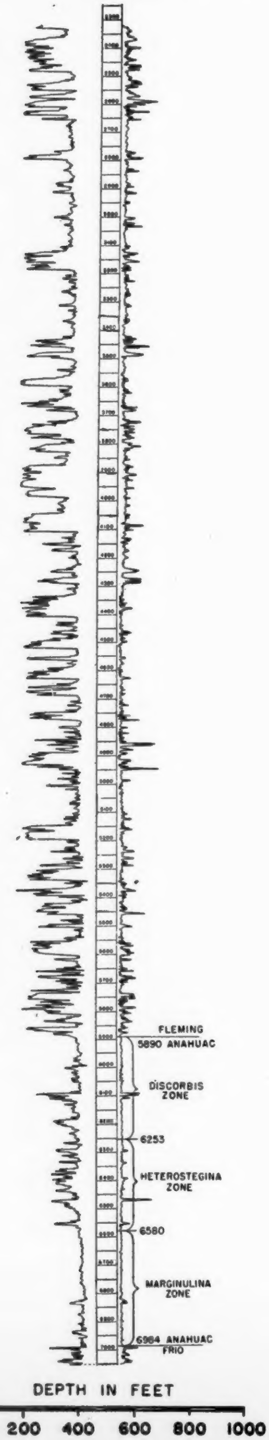
The Mayo-Baker's Gibbs No. 1 begins in the Catahoula formation about a mile north of the contact with the Fleming formation. The two "rice" sand horizons in the basal part of the Catahoula section in Gibbs No. 1 and in the Bunn-Continental's Oliphant No. 1 are correlative with the sandstones on the surface mapped as the Dunlap Quarry sandstone and the Chita sandstone. These "rice sand" horizons are no doubt the equivalents of the "rice sand" series in Deering *et al.* Randolph No. 1 below 2,400 feet and in Jack Frazier's Santa Fe Tie and Lumber Company No. 1 below 2,600 feet. The section shows that the subsurface Frio is the equivalent of the surface Catahoula.

The last definite Vicksburg fossils are found in the Cockburn Oil Corporation's Dixon-Falvey No. 1. Updip from this well the base of the lowermost "rice" sand is used to determine the contact of the Frio with the Vicksburg. The top of a pelecypod horizon in beds mapped as Jackson on the surface by S. O. Burford and Perry Olcott grades into the top of the Jackson in the subsurface. This horizon is at the base of the upper 180–200 feet of the beds that were mapped as Jackson and were called the "uppermost Fayette section" by Burford and Olcott. This "uppermost Fayette section" of Burford and Olcott is believed to be the equivalent of the subsurface Vicksburg. Diatoms and a few arenaceous Foraminifera are found in these brown lignitic clays.

[17] B. Coleman Renick, "The Jackson Group and the Catahoula and Oakville Formations in a Part of the Texas Gulf Coastal Plain," *Univ. Texas Bull. 3619* (1936), pp. 62–64.

FIGURE 2
TYPE LOG

HUMBLE OIL & REFINING CO.
A. D. MIDDLETON NO. 1
ANAHUAC
CHAMBERS CO.



LITHOLOGY

The Anahuac at the type locality in the Humble Oil and Refining Company's Middleton No. 1 consists of dark, greenish gray, slightly micaceous calcareous shale with very fine partings of sand. Lenses of sand and calcareous sand are interlaminated with the shale.

The electrical log (Fig. 2), shows a well defined lithologic pattern of shale with sand lenses between two essentially sandy formations.

The formation is divided into three faunal units, the *Discorbis*, the *Heterostegina*, and the *Marginulina* zones. Because the *Discorbis* zone is very sandy in some areas, the contact with the Fleming is difficult to determine on the electrical log. Also in the basal Fleming downdip, brackish-water and lignitic shale lenses are interlaminated with the sands. In these shale lenses are oysters, ostracods, *Rotalia beccarii*, *Discorbis subauracana* var. *dissona*, reworked Cretaceous material and here and there one or two species of the *Discorbis* zone. Some paleontologists include these beds in the *Discorbis* zone.

Around some of the salt domes, as already stated, the facies of the *Heterostegina* zone is a reef limestone. In some areas, the *Heterostegina* zone is principally sand. The *Marginulina* zone is predominantly shale with lenses of sand.

FAUNA

The fauna of the Anahuac formation is incompletely described. Only the more or less diagnostic species have been published. The *Discorbis* zone is characterized by an association of the following.

Discorbis gravelli Garrett
Discorbis subauracana Cushman
Discorbis subauracana Cushman var. *dissona* Cushman and Ellisor
Discorbis nomada Garrett
Siphonina davisi Cushman and Ellisor
Textularia teasi Cushman and Ellisor
Virgulina exilis Cushman and Ellisor
Robulus chambersi Garrett
Lenticulina jeffersonensis Garrett
Bifarina vicksburgensis (Cushman) var. *monsouri* Garrett
Siphogenerina fredsmithi Garrett
Cibicides moreyi Garrett
Cibicides jeffersonensis Garrett
Gyroidina vicksburgensis (Cushman) var. *hannai* Garrett
Uvigerina howei Garrett
Uvigerina pilulata Cushman and Ellisor

The *Heterostegina* zone is identified by means of *Heterostegina texana* Gravell and Hanna, and *Heterostegina israelskyi* Gravell and Hanna. In addition, the described species in this zone are the following.

Operculinoides ellisorae Gravell and Hanna
Operculinoides howei Gravell and Hanna
Lepidocyclina (*Lepidocyclina*) *colei* Gravell and Hanna

Lepidocyclina (*Lepidocyclina*) *texana* Gravell and Hanna
Discorbis gravelli Garrett
Gyroidina vicksburgensis (Cushman) var. *hannai* Garrett
Eponides ellisorae Garrett
Textularia mornhinvegi Garrett
Vulvulina ignava Garrett
Marginulina idiomorpha Garrett
Robulus lacerta Garrett
Robulus chambersi Garrett
Bolivina perca Garrett
Uvigerina israelskyi Garrett
Bifarina vicksburgensis (Cushman) var. *monsouri* Garrett

Only a few species of the *Marginulina* fauna have been described. *Marginulina vaginata* Garrett and Ellis is the diagnostic species. Both *Marginulina idiomorpha* Garrett and *Marginulina howei* Garrett and Ellis occur in this zone. There is a characteristic small *Uvigerina*, also an inflated *Siphonina*, both undescribed, which are abundant in the *Marginulina* zone and which can be used to identify the zone. Some of the species from the *Heterostegina* zone are present, such as *Eponides ellisorae*, *Robulus lacerta*, *Bolivina perca* Garrett, *Cibicides moreyi* Garrett, and *Discorbis gravelli* Garrett.

For the convenience of paleontologists the plates showing the fossils which have been described are here reproduced. Marcus A. Hanna very kindly made up some new plates of the larger fossils published by him and Donald W. Gravell. Garrett's and Ellis' plates are reproduced just as they were published. On the plates showing the various *Marginulina* species is *Marginulina texana* which is not an Anahuac species but a Frio species, and *Marginulina mexicana* of the Meson formation of Mexico.

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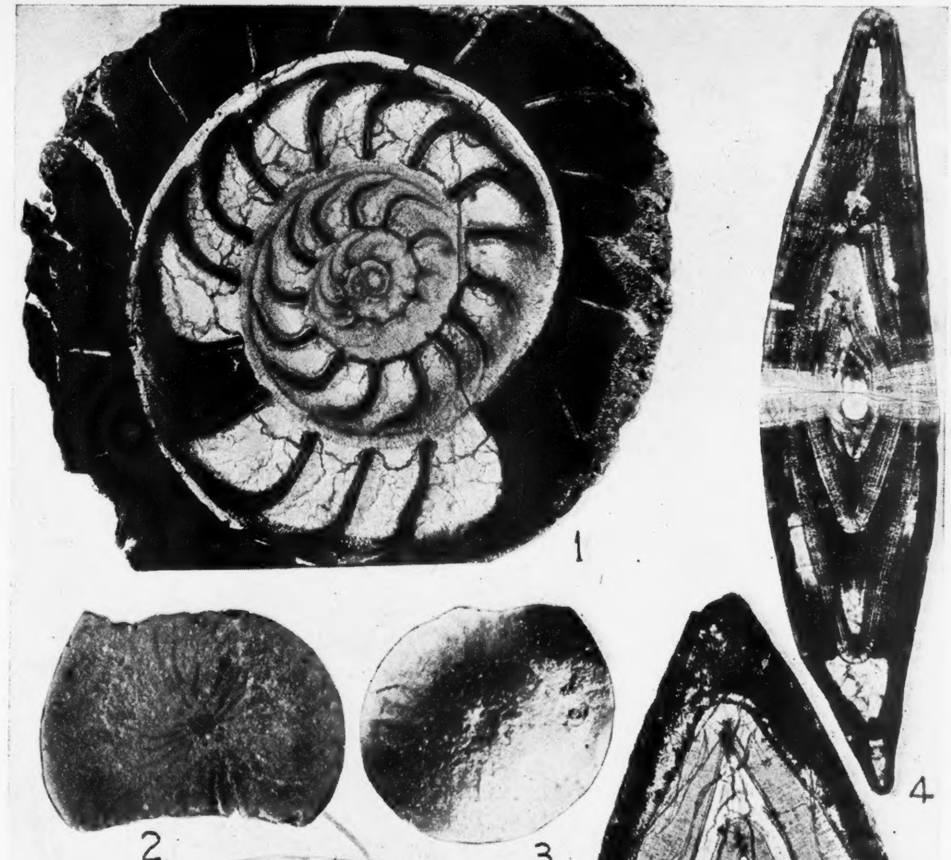

PLATE 1.—All figures after Donald W. Gravell and Marcus A. Hanna, "The *Lepidocyclina texana* Horizon in the *Heterostegina* Zone Upper Oligocene, of Texas and Louisiana," *Jour. Paleon.*, Vol. 11, No. 6 (September, 1937).

Fig. 1.—*Operculinoides howei* Gravell and Hanna. Syntype, thin section in median plane. ×50.
Fig. 2.—*Operculinoides ellisorae* Gravell and Hanna. Syntype, surface view. ×18.
Fig. 3.—*Operculinoides howei* Gravell and Hanna. Syntype, surface view. ×18.
Fig. 4.—*Operculinoides ellisorae* Gravell and Hanna. Syntype, vertical thin section. ×50.
Fig. 5.—*Operculinoides ellisorae* Gravell and Hanna. Syntype, half section in median plane. ×50.
Fig. 6.—*Operculinoides howei* Gravell and Hanna. Syntype, vertical thin section. ×50.
All specimens from core at 7,356–7,366 feet in the Sun Oil Company's Hamilton No. 1, J. T. White Survey, Chambers County, Texas.

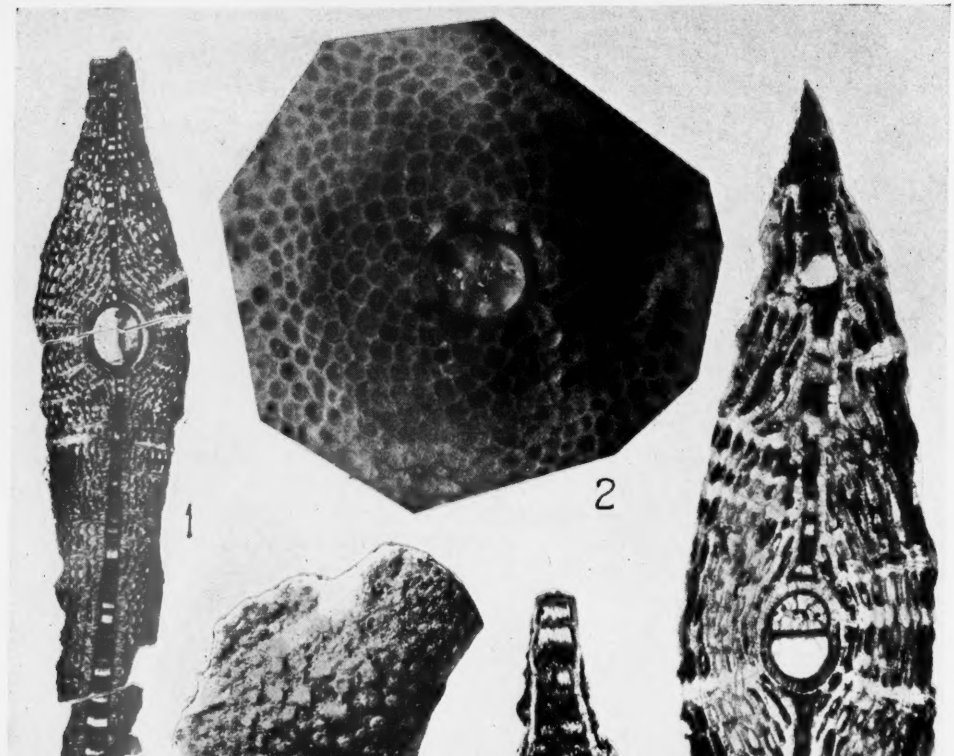

PLATE 2.—All figures after Donald W. Gravell and Marcus A. Hanna, "The *Lepidocyclina texana* Horizon in the *Heterostegina* Zone, Upper Oligocene, of Texas and Louisiana," *Jour. Paleon.*, Vol. 11, No. 6 (September, 1937).

Fig. 1.—*Lepidocyclina* (*Lepidocyclina*) *texana* Gravell and Hanna. Syntype, vertical thin section. ×18.

Fig. 2.—*Lepidocyclina* (*Lepidocyclina*) *colei* Gravell and Hanna. Syntype, half section cut in median plane. ×50.

Fig. 3.—*Lepidocyclina* (*Lepidocyclina*) *colei* Gravell and Hanna. Syntype, surface view. ×18.

Fig. 4.—*Lepidocyclina* (*Lepidocyclina*) *texana* Gravell and Hanna. Syntype, surface view. ×10.

Fig. 5.—*Lepidocyclina* (*Lepidocyclina*) *texana* Gravell and Hanna. Syntype, thin section cut across one of the rays. ×50.

Fig. 6.—*Lepidocyclina* (*Lepidocyclina*) *colei* Gravell and Hanna. Syntype, vertical thin section. ×50.

Figures 1 and 4 from core from 7,366–7,368 feet, and Figures 2, 3, 5, and 6 from core from 7,366–7,376 feet in the Sun Oil Company's Hamilton No. 1, J. T. White Survey, Chambers County, Texas.

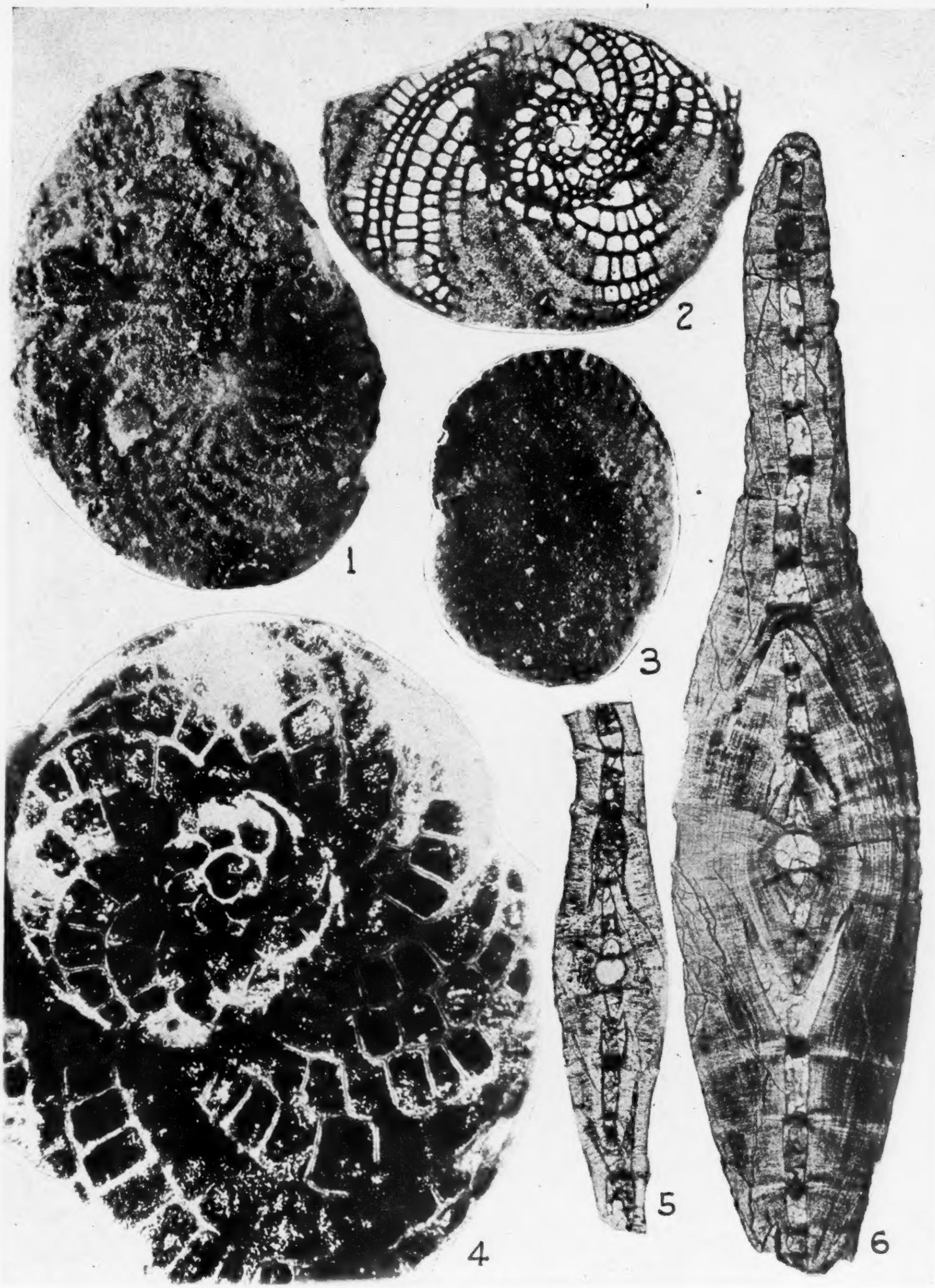

PLATE 3.—All figures after Donald W. Gravell and Marcus A. Hanna, "The *Lepidocyclina texana* Horizon in the *Heterostegina* Zone, Upper Oligocene, of Texas and Louisiana," *Jour. Paleon.*, Vol. 11, No. 6 (September, 1937).

Fig. 1.—*Heterostegina texana* Gravell and Hanna. Syntype, surface view. ×18.
Fig. 2.—*Heterostegina texana* Gravell and Hanna. Syntype, thin section in median plane. ×18.
Fig. 3.—*Heterostegina israelskyi* Gravell and Hanna. Syntype, surface view. ×18.
Fig. 4.—*Heterostegina israelskyi* Gravell and Hanna. Syntype, thin section in median plane of megalospheric form. ×50.
Fig. 5.—*Heterostegina israelskyi* Gravell and Hanna. Syntype, vertical thin section of megalospheric form. ×50.
Fig. 6.—*Heterostegina texana* Gravell and Hanna. Syntype, vertical thin section. ×50.

Figures 3, 4, and 5 from core from 7,336–7,346 feet, and Figures 1, 2, and 6 from core from 7,366–7,376 feet in the Sun Oil Company's Hamilton No. 1, J. T. White Survey, Chambers County, Texas.

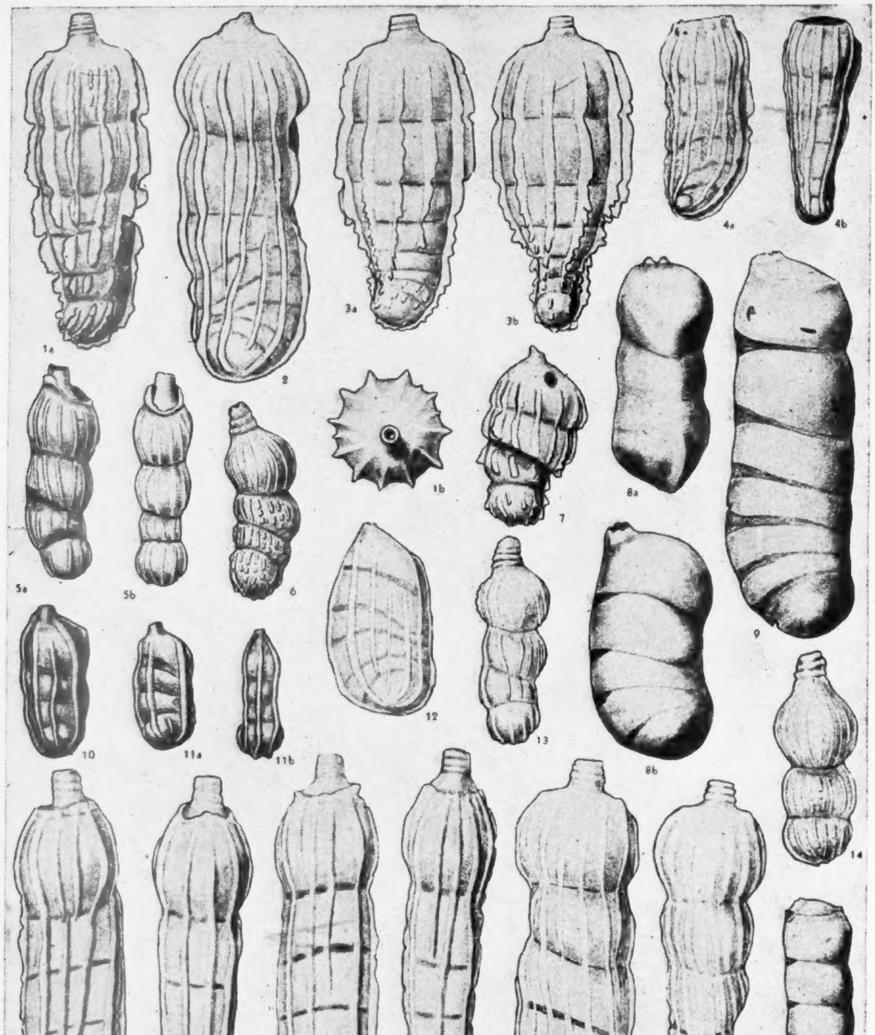

PLATE 4.—All figures after J. B. Garrett and A. D. Ellis, Jr., "Distinctive Foraminifera of the Genus *Marginulina* from Middle Tertiary Beds of the Gulf Coast," *Jour. Paleon.*, Vol. 11, No. 8 (December, 1937), Pl. 86.

Figs. 1a, 1b, 3a, 3b, 7.—*Marginulina texana* Garrett and Ellis, n. sp. 1a, side view; 1b, apertural view, paratype no. 1, 914, ×56. 3a, Side view; 3b, front view, holotype no. 1,913, ×55. 7, Side view, paratype no. 1,915, ×56, young specimen. Middle Tertiary, Texas.

Figs. 2, 10, 11a, 11b, 12, 17a, 17b.—*Marginulina mexicana* Cushman var. *vaginata* Garrett and Ellis, n. var. 2, Side view, paratype no. 1,907, ×57, megalospheric form. 10, Side view, paratype no. 1,906, ×46, dwarf specimen. 11a, Side view; 11b, front view, paratype no. 1,905, ×46, dwarf specimen. 12, Side view, paratype no. 1,908, ×57, young specimen. 17a, Side view; 17b, front view, holotype no. 1,904, ×60, megalospheric form. Middle Tertiary, Texas.

Figs. 4a, 4b, 15a–16b.—*Marginulina mexicana* Cushman. 4a, Side view; 4b, front view, metatype no. 1,901, ×48. 15a, Side view; 15b, front view, megalospheric form, hypotype no. 1,902, ×57. 16a, Side view; 16b, front view, microspheric form, hypotype no. 1,903, ×60. Meson formation, Mexico.

Figs. 5a, b, 6, 13, 14.—*Marginulina idiomorpha* Garrett and Ellis, n. sp. 5a, Side view; 5b, front view, paratype no. 1,910, ×57. 6, Side view, paratype no. 1,912, ×55. 13, Side view, holotype no. 1,909, ×57. 14, Side view, paratype no. 1,911, ×54. Middle Tertiary, Texas.

Figs. 8a, b, 9, 18.—*Marginulina howei* Garrett and Ellis, n. sp. 8a, Front view; 8b, side view, paratype no. 1,918, ×55, young specimen. 9, Side view, holotype no. 1,916, ×55. 18, Side view, paratype no. 1,917, very elongate specimen, ×26. Middle Tertiary, Louisiana.

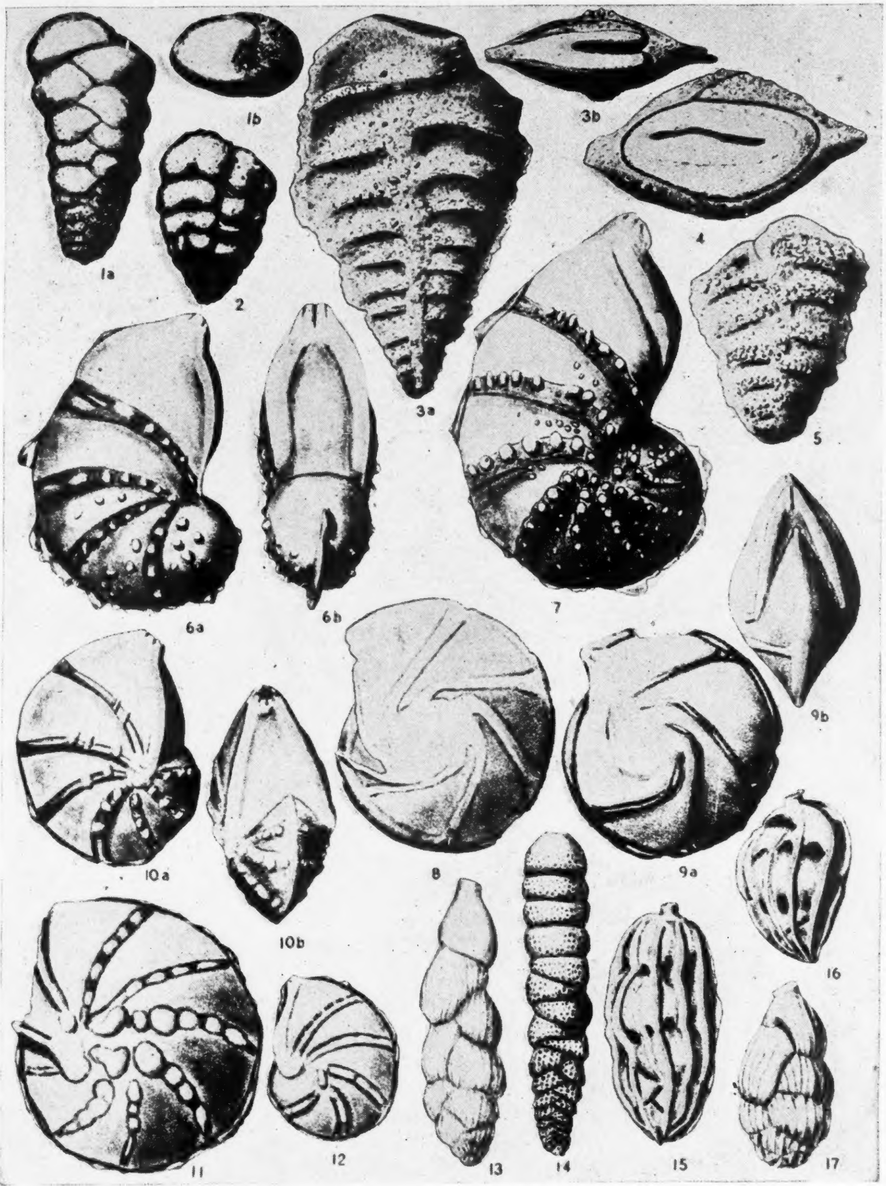

PLATE 5.—All figures after J. B. Garrett, "Some Middle Tertiary Smaller Foraminifera from Subsurface Beds of Jefferson County, Texas," *Jour. Paleon.*, Vol. 13, No. 6 (November, 1939), Pl. 65.

Figs. 1a–b, 2.—*Textularia mornhinvegi* Garrett, n. sp. 1a, Side view; 1b, apertural view, syntype no. 1,935, ×25. 2, Side view, syntype no. 1,936, ×25. *Heterostegina* zone, middle Tertiary, Texas.

Figs. 3a–b, 4, 5.—*Vulvulina ignava* Garrett, n. sp. 3a, Side view; 3b, apertural view, syntype no. 1,937, ×54. 4, Apertural view, syntype no. 1,939, ×54. 5, Side view, syntype no. 1,938, ×52. *Marginulina idiomorpha* zone, middle Tertiary, Texas.

Figs. 6a–b, 7.—*Robulus lacerta* Garrett, n. sp. 6a, Side view; 6b, apertural view, paratype no. 1,943, ×67. 7, Side view, holotype no. 1,942, ×55. *Marginulina idiomorpha* zone, middle Tertiary, Texas.

Figs. 8, 9a–b.—*Robulus chambersi* Garrett, n. sp. 8, Side view, syntype no. 1,941, ×55. 9a, Side view; 9b, apertural view, syntype no. 1,940, ×54. *Discorbis* zone, middle Tertiary, Texas.

Figs. 10a–b, 11, 12.—*Lenticulina jeffersonensis* Garrett, n. sp. 10a, Side view; 10b, apertural view, syntype no. 1,945, ×52, young specimen. 11, Side view, syntype no. 1,944, ×54. 12, Side view, syntype, no. 1,946, ×66, young specimen. *Discorbis* zone, middle Tertiary, Texas.

Figs. 13, 17.—*Uvigerina howei* Garrett, n. sp. 13, Side view, paratype no. 1,949, ×69. 17, Side view, holotype no. 1,948, ×70. *Discorbis* zone, middle Tertiary, Texas.

Fig. 14.—*Bifarina vicksburgensis* (Cushman) var. *monsouri* Garrett, n. var. Side view, holotype no. 1,947, ×70. *Discorbis* zone, middle Tertiary, Texas.

Figs. 15, 16.—*Uvigerina israelskyi* Garrett, n. sp. 15, Side view, holotype no. 1,950, ×54. 16, Side view, paratype no. 1,951, ×50 young specimen. *Heterostegina* zone, middle Tertiary, Texas.

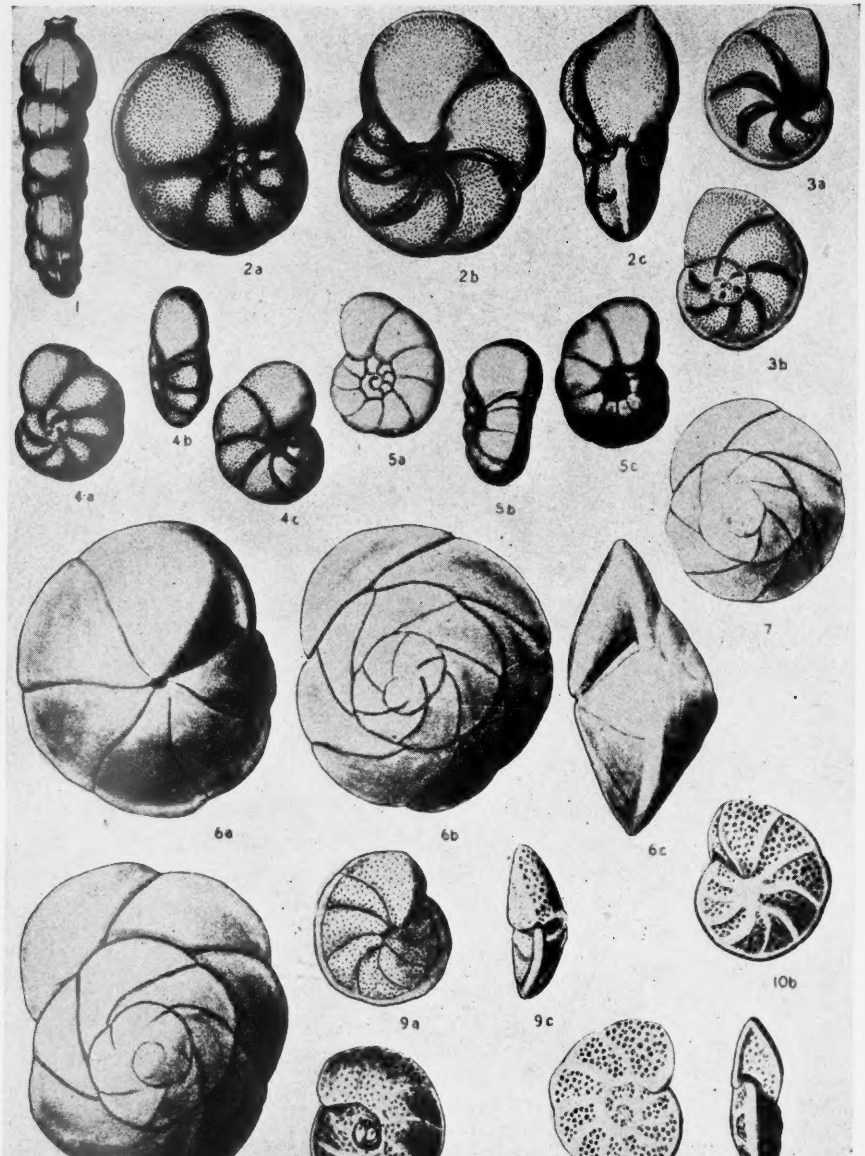

PLATE 6.—All figures after J. B. Garrett, "Some Middle Tertiary Smaller Foraminifera from Subsurface Beds of Jefferson County, Texas," *Jour. Paleon.*, Vol. 13, No. 6 (November, 1939), Pl. 66.

Fig. 1.—*Siphogenerina fredsmithi* Garrett, n. sp. Side view, holotype no. 1,952, ×67. *Discorbis* zone, middle Tertiary, Texas.

Figs. 2a–c, 3a–b.—*Discorbis gravelli* Garrett, n. sp. 2a, Dorsal view; 2b, ventral view; 2c, apertural view, holotype no. 1,953, ×54. 3a, ventral view; 3b, dorsal view, paratype no. 1,954, ×66, young speciman. *Discorbis* zone, middle Tertiary, Texas.

Figs. 4a–c.—*Discorbis nomada* Garrett, n. sp. 4a, Dorsal view; 4b, apertural view; 4c, ventral view, holotype no. 1,955, ×66. *Discorbis* zone, middle Tertiary, Texas.

Figs. 5a–c.—*Gyroidina vicksburgensis* (Cushman) var. *hannai* Garrett, n. var. 5a, Dorsal view; 5b, apertural view; 5c, ventral view, holotype no. 1,956, ×52. *Discorbis* zone, middle Tertiary, Texas.

Figs. 6a–c, 7, 8.—*Eponides ellisorae* Garrett, n. sp. 6a, Ventral view; 6b, dorsal view; 6c, apertural view, holotype no. 1,957, ×52. *Marginulina idiomorpha* zone, middle Tertiary, Texas. 7, Dorsal view, paratype no. 1,959, ×54. *Discorbis* zone, middle Tertiary, Texas. 8, Dorsal view, paratype no. 1,958, ×51. *Marginulina idiomorpha* zone, middle Tertiary, Texas.

Figs. 9a–c.—*Cibicides moreyi* Garrett, n. sp. 9a, Ventral view; 9b, dorsal view; 9c, apertural view, holotype no. 1,961, ×70. *Discorbis* zone, middle Tertiary, Texas.

Figs. 10a–c.—*Cibicides jeffersonensis* Garrett, n. sp. 10a, Dorsal view; 10b, ventral view; 10c, apertural view, holotype no. 1,960 ×68. *Discorbis* zone, middle Tertiary, Texas.

PLATE 7.—All figures except 10, 11 and 12a, b, c, after Alva C. Ellisor, "Subsurface Miocene of Southern Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 3 (March, 1940), Pl. 1, p. 465.

Figures 10, 11, 12a, b, c, after J. B. Garrett, *Jour. Paleon.*, Vol. 12, No. 4 (July, 1938).

Fig. 1.—*Textularia teasi* Cushman and Ellisor. ×45.

Fig. 2.—*Bolivina tenuistriata* Cushman and Ellisor. ×55.

Fig. 3.—*Virgulina exilis* Cushman and Ellisor. ×55.

Fig. 4.—*Uvigerina pilulata* Cushman and Ellisor. ×65.

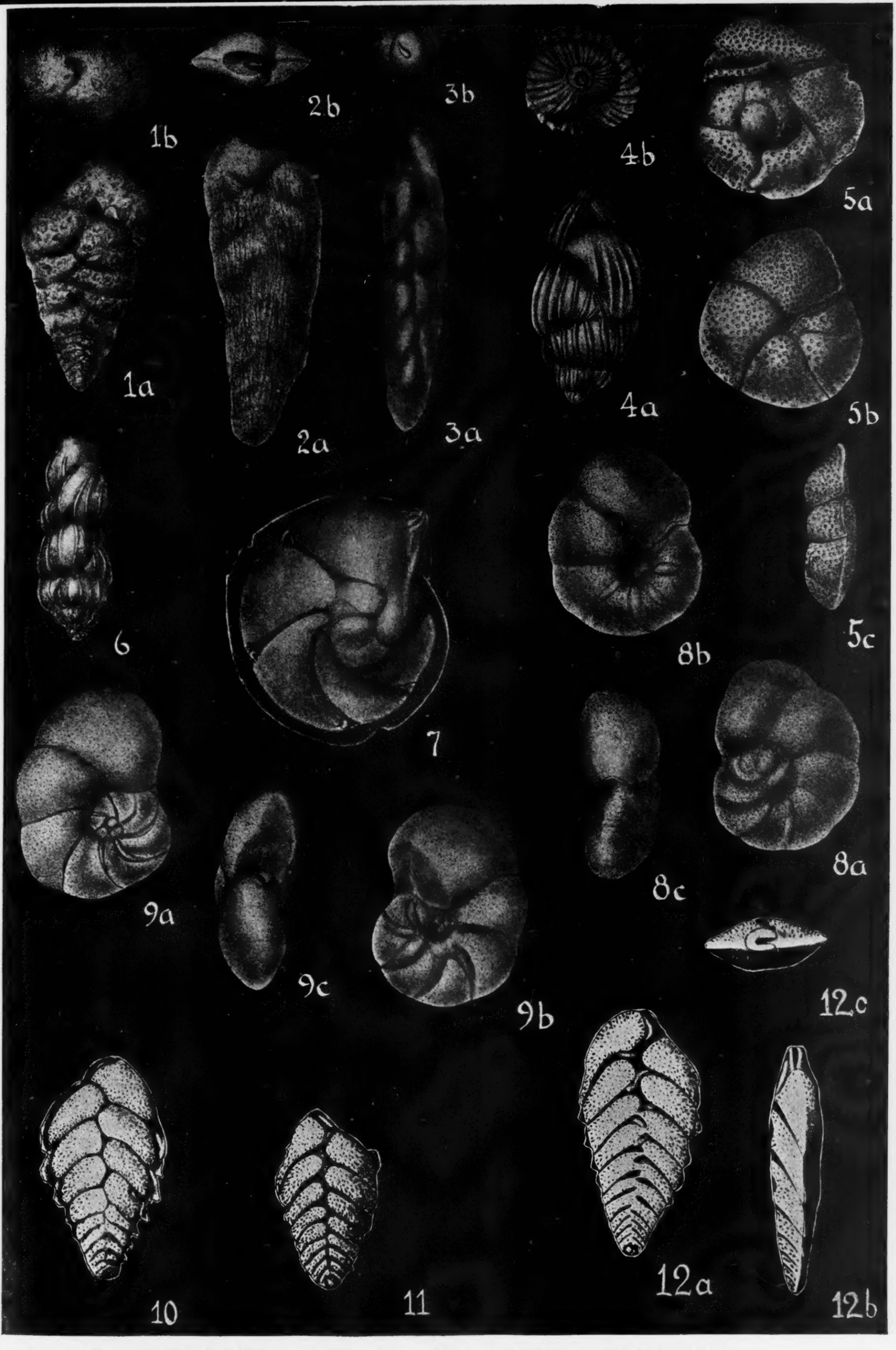

PLATE 7.—Fig. 5.—*Siphonina davisi* Cushman and Ellisor. ×60. Fig. 6.—*Angulogerina byramensis* (Cushman). ×65.
Fig. 7.—*Robulus clericii* (Fornasini). ×60. Fig. 8.—*Discorbis subauracana* Cushman. ×65.
Fig. 9.—*Discorbis subauracana* Cushman, var. *dissona* Cushman and Ellisor. ×65.
Figs. 10, 11, 12a, b, c.—*Bolivina perca* Garrett, n. sp. 12a, Side view; 12c, apertural view; 12b, edge view, holotype no. 1,926, ×55. 10, Side view, paratype no. 1,927, ×55. 11, Side view, paratype no. 1,928, ×55. *Marginulina idiomorpha* zone, middle Tertiary, Texas.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 9 (SEPTEMBER, 1944), PP. 1376-1396, 9 FIGS., 1 PLATE

GEOLOGICAL NOTES

CALCULATION OF STRATIGRAPHIC THICKNESS IN PARALLEL FOLDS[1]

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Washington, D. C.

INTRODUCTION

The calculation of the thickness of strata is, for the writer, a topic of perennial interest. The general problem has numerous aspects. Assuming the existence of a folded sequence of rocks, wherein the stratigraphic surfaces are essentially parallel, one may wish merely to compute a stratigraphic thickness between two stations, considering that the dip is variable and the strike is constant, or *vice versa*. Both of these are profile problems, confined to two dimensions, and may be solved by any of several simple methods, that are too well known to require discussion. All such methods, however, are empirical, because some assumption is tacitly made regarding the curvature of the fold, whereas in fact the nature of the curvature is quite unknown.

Still holding to two dimensions, one may wish to consider three or more station points simultaneously, in order to construct a profile through the fold, showing the trace of the true curvature of the strata. This problem, as shown by the writer,[3] may be solved either geometrically or analytically by means of the theory of evolutes and involutes; and if sufficient data are available, this method can be regarded as exact, instead of empirical.

Where the strike and dip vary from point to point, the problem takes on its most general aspect, and becomes three-dimensional. In this form, empirical methods of solution are almost necessarily required, because any exact solution will involve a consideration of parallel surfaces; and such solutions, either geometrical or analytical, are difficult in theory and laborious in practice, rendering them unsuitable for general utilization. The oldest and most commonly used method for measuring the stratigraphic thickness between two stations, where both the strike and dip are different, is to apply the mean values of strike and dip in some formula that is used for calculating stratigraphic thickness in a homoclinal sequence of beds. This method is satisfactory if the variations in strike and dip are not too great. Other three-dimensional empirical methods have been proposed

[1] Published with the permission of the director of the Geological Survey, United States Department of the Interior. Manuscript received, May 22, 1944.

[2] Geological Survey.

[3] J. B. Mertie, Jr., "Stratigraphic Measurements in Parallel Folds," *Bull. Geol. Soc. America*, Vol. 51 (1940), pp. 1113–22.

by Ickes,[4] Eardley,[5] and the writer.[6] It is now desired, for reasons stated below, to present still another method for solving this three-dimensional problem.

NEW METHOD

One of the two-dimensional methods for measuring the stratigraphic thickness of folded beds, is the method of circular arcs, proposed originally by Hewett,[7] and illustrated in Figure 1. While the strike is considered to remain constant at

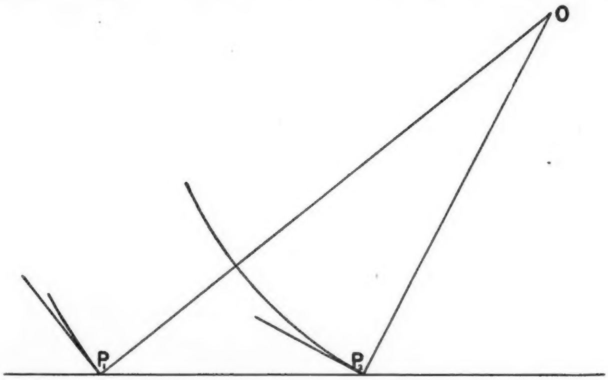


FIG. 1.—Hewett's method of determining stratigraphic thickness by means of concentric arcs.

two station points, traces of the planes tangent to the stratigraphic surfaces are drawn in a vertical profile normal to these tangent planes. Through the station points P_1 and P_2, perpendiculars are then erected that intersect at O. With O as a center, circular arcs are drawn through P_1 and P_2; and the stratigraphic thickness is defined as $\overline{OP}_1-\overline{OP}_2$. For computing numerically the stratigraphic thickness, an algebraic formula corresponding with this construction has also been derived.

This method, for two reasons, gives only an approximation to the true thickness. First, it is two-dimensional instead of three-dimensional; and second, it assumes in those two dimensions a circular curvature for the traces of the beds, whereas in fact the true curvature is unknown. But it is certianly true that some curvature exists in the folded beds; and as two station points do not suffice for determining the true curvature, the fitting of these two station points onto circular arcs seems entirely warranted. Therefore, Hewett's solution is considered by the writer to be the best of the two-dimensional empirical methods.

[4] E. L. Ickes, "The Determination of Formation Thicknesses by the Method of Graphical Integration," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), pp. 451–63.

[5] A. J. Eardley, "Graphic Treatment of Folds in Three Dimensions," *ibid.*, Vol. 22 (1938), pp. 483–89.

[6] J. B. Mertie, Jr., *op. cit.*, pp. 1122–32.

[7] D. F. Hewett, "Measurements of Folded Beds," *Econ. Geol.*, Vol. 15 (1920), pp. 367–85.

The method demonstrated in this paper is an attempt to apply the underlying principle of Hewett's method in three dimensions. If the curvature of two parallel stratigraphic surfaces were spherical, normals to these surfaces at the two station points would intersect in a point. For non-spherical parallel surfaces, however, normals drawn to the surfaces at any two station points P_1 and P_2 will be skew lines. Hence, no center is defined from which concentric circular arcs or spherical surfaces can be constructed. But it is possible to draw one line that is perpendicular to both skew lines, at the points where these lines approach most closely to each other (Fig. 2). The intersection of this line with the skew lines de-

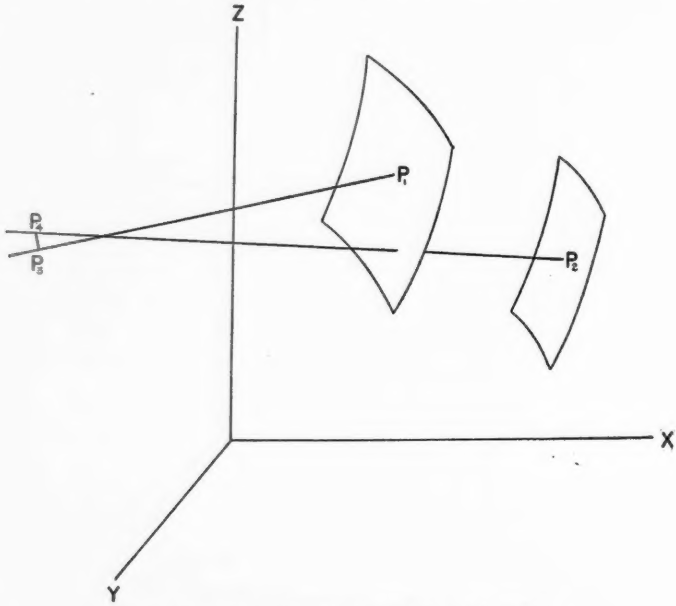


FIG. 2.—Skew lines normal to two stratigraphic surfaces.

fines two other points, P_3 and P_4, from which circular arcs or spherical surfaces may be constructed that pass through the two station points. In other words, the points P_3 and P_4 may be considered as a center of curvature, that was divided as the stratigraphic surfaces diverged from sphericity. And the length of the perpendicular, connecting the skew lines, may be regarded as a measure of the departure of the curvature from sphericity. Thus two centers of projection instead of one will exist, and the stratigraphic thickness will be defined as $\overline{P_2P_4}-\overline{P_1P_3}$. The following demonstration shows how the lengths $\overline{P_2P_4}$ and $\overline{P_1P_3}$ may be computed.

This method, though simple in principle, is rather laborious in practice.

Therefore, it is not presented as a substitute for the older methods. But it is believed that this method will yield a closer approximation to the true stratigraphic thickness than any other three-dimensional empirical method yet proposed. Hence, it is offered as a method of superior accuracy that may be used when the character of the work warrants its application.

DERIVATION OF FORMULAE

Let P_1 and P_2 be two station points, located on two stratigraphic surfaces, that are considered to be essentially parallel; and let two planes, tangent to the stratigraphic surfaces at P_1 and P_2, be defined by their strikes and dips. To the points P_1 and P_2 are assigned the coördinates, respectively, of (x_1, y_1, z_1) and (x_2, y_2, z_2), in some system of three-dimensional rectangular coördinates.

At P_1 and P_2 erect normals to the stratigraphic surfaces, having the direction angles $\alpha_1, \beta_1, \gamma_1$ and $\alpha_2, \beta_2, \gamma_2$. The values of the direction cosines $\cos \alpha_1$, $\cos \alpha_2$, $\cos \beta_1$, and $\cos \beta_2$ may readily be obtained by solving four spherical quadrantal equations, defined by the Z axis (or a parallel with same), the two normals, and the X and Y axes (or parallels with same). These solutions require the equations

$$\cos \alpha_0 = \cos A_0 \sin \delta_0 \quad \text{and} \quad \cos \beta_0 = \cos B_0 \sin \delta_0$$

where A_0 and B_0 are the angles between the strikes and the X (or Y) axes and δ_0 is the angle of dip at any station.

The direction cosines $\cos \gamma_1$ and $\cos \gamma_2$ are equal to $\cos \delta_1$ and $\cos \delta_2$, where δ_1 and δ_2 are the angles of dip at stations P_1 and P_2.

The two normals erected at P_1 and P_2 are skew lines, whose equations may be written as follows.

$$\frac{x - x_1}{\cos \alpha_1} = \frac{y - y_1}{\cos \beta_1} = \frac{z - z_1}{\cos \gamma_1} \tag{1}$$

$$\frac{x - x_2}{\cos \alpha_2} = \frac{y - y_2}{\cos \beta_2} = \frac{z - z_2}{\cos \gamma_2}\,. \tag{2}$$

It is now desired to obtain the equation of a plane that passes through the first skew line, and is parallel with the second; and also the equation of a plane that passes through the second skew line, and is parallel with the first. One and only one common perpendicular can be drawn to both skew lines; and the direction cosines of that line will be the coëfficients of the three variables in the two equations of the desired parallel planes. These direction cosines may be obtained by solving the three following equations.

$$\cos \alpha_1 \cos \alpha + \cos \beta_1 \cos \beta + \cos \gamma_1 \cos \gamma = 0 \tag{3}$$

$$\cos \alpha_2 \cos \alpha + \cos \beta_2 \cos \beta + \cos \gamma_2 \cos \gamma = 0 \tag{4}$$

$$\cos^2 \alpha + \cos^2 \beta + \cos^2 \gamma = 1. \tag{5}$$

From the equations (3) and (4), we obtain the following.

$$K \cos \alpha = \cos \beta_1 \cos \gamma_2 - \cos \beta_2 \cos \gamma_1$$
$$K \cos \beta = \cos \gamma_1 \cos \alpha_2 - \cos \gamma_2 \cos \alpha_1$$
$$K \cos \gamma = \cos \alpha_1 \cos \beta_2 - \cos \alpha_2 \cos \beta_1$$

where

$$K = \frac{\cos \alpha_2 \cos \gamma_1 - \cos \alpha_1 \cos \gamma_2}{\cos \beta}.$$

But

$$\sin^2 \theta = (\cos \beta_1 \cos \gamma_2 - \cos \beta_2 \cos \gamma_1)^2 + (\cos \gamma_1 \cos \alpha_2 - \cos \gamma_2 \cos \alpha_1)^2 + (\cos \alpha_1 \cos \beta_2 - \cos \alpha_2 \cos \beta_1)^2$$

where θ is the angle between the directions of the two skew lines.
Hence,

$$\sin^2 \theta = K^2(\cos^2 \alpha + \cos^2 \beta + \cos^2 \gamma), \quad \text{whence} \quad \sin \theta = K$$
$$\therefore \quad \cos \alpha = (\cos \beta_1 \cos \gamma_2 - \cos \beta_2 \cos \gamma_1) \operatorname{cosec} \theta$$
$$\cos \beta = (\cos \gamma_1 \cos \alpha_2 - \cos \gamma_2 \cos \alpha_1) \operatorname{cosec} \theta$$
$$\cos \gamma = (\cos \alpha_1 \cos \beta_1 - \cos \alpha_2 \cos \beta_1) \operatorname{cosec} \theta.$$

The equations of the two parallel planes may therefore be written as follows.

$$(x - x_1)(\cos \beta_1 \cos \gamma_2 - \cos \beta_2 \cos \gamma_1) + (y - y_1)(\cos \gamma_1 \cos \alpha_2 - \cos \gamma_2 \cos \alpha_1) + (z - z_1)(\cos \alpha_1 \cos \beta_2 - \cos \alpha_2 \cos \beta_1) = 0 \tag{6}$$

$$(x - x_2)(\cos \beta_1 \cos \gamma_2 - \cos \beta_2 \cos \gamma_1) + (y - y_2)(\cos \gamma_1 \cos \alpha_2 - \cos \gamma_2 \cos \alpha_1) + (z - z_2)(\cos \alpha_1 \cos \beta_2 - \cos \alpha_2 \cos \beta_1) = 0. \tag{7}$$

Now pass a plane through each of the skew lines, perpendicular to the parallel planes represented by equations (6) and (7). These two perpendicular planes will intersect in, and will define the equation of, the perpendicular to the two skew lines, which is the shortest distance between them. These two planes may be represented by the two following determinants.

$$\begin{vmatrix} x & y & z & 1 \\ x_1 & y_1 & z_1 & 1 \\ \cos \beta_1 \cos \gamma_2 - \cos \beta_2 \cos \gamma_1 & \cos \gamma_1 \cos \alpha_2 - \cos \gamma_2 \cos \alpha_1 & \cos \alpha_1 \cos \beta_2 - \cos \alpha_2 \cos \beta_1 & 0 \\ \cos \alpha_1 & \cos \beta_1 & \cos \gamma_1 & 0 \end{vmatrix} = 0.$$

$$\begin{vmatrix} x & y & z & 1 \\ x_2 & y_2 & z_2 & 1 \\ \cos \beta_1 \cos \gamma_2 - \cos \beta_2 \cos \gamma_1 & \cos \gamma_1 \cos \alpha_2 - \cos \gamma_2 \cos \alpha_1 & \cos \alpha_1 \cos \beta_2 - \cos \alpha_2 \cos \beta_1 & 0 \\ \cos \alpha_2 & \cos \beta_2 & \cos \gamma_2 & 0 \end{vmatrix} = 0.$$

Expanding these determinants, and substituting in them the expression

$$\cos\theta = \cos\alpha_1 \cos\alpha_2 + \cos\beta_1 \cos\beta_2 + \cos\gamma_1 \cos\gamma_2,$$

we obtain,

$$(x - x_1)(\cos\alpha_2 - \cos\theta\cos\alpha_1) + (y - y_1)(\cos\beta_2 - \cos\theta\cos\beta_1) + (z - z_1)(\cos\gamma_2 - \cos\theta\cos\gamma_1) = 0 \quad (8)$$

$$(x - x_2)(\cos\alpha_1 - \cos\theta\cos\alpha_2) + (y - y_2)(\cos\beta_1 - \cos\theta\cos\beta_2) + (z - z_2)(\cos\gamma_1 - \cos\theta\cos\gamma_2) = 0. \quad (9)$$

But the coördinate axes may always be so chosen that the point P_1 lies at the origin, and the point P_2 lies in one of the axial planes, say in the YZ plane. Then $x_1 = y_1 = z_1 = x_2 = 0$, and the equations of the parallel planes and of the two planes perpendicular to them reduce to the following.

$$x(\cos\beta_1\cos\gamma_2 - \cos\beta_2\cos\gamma_1) + y(\cos\gamma_1\cos\alpha_2 - \cos\gamma_2\cos\alpha_1) + z(\cos\alpha_1\cos\beta_2 - \cos\alpha_2\cos\beta_1) = 0 \quad (10)$$

$$x(\cos\beta_1\cos\gamma_2 - \cos\beta_2\cos\gamma_1) + (y - y_2)(\cos\gamma_1\cos\alpha_2 - \cos\gamma_2\cos\alpha_1) + (z - z_2)(\cos\alpha_1\cos\beta_2 - \cos\alpha_2\cos\beta_1) = 0 \quad (11)$$

$$x(\cos\alpha_2 - \cos\theta\cos\alpha_1) + y(\cos\beta_2 - \cos\theta\cos\beta_1) + z(\cos\gamma_2 - \cos\theta\cos\gamma_1) = 0 \quad (12)$$

$$x(\cos\alpha_1 - \cos\theta\cos\alpha_2) + (y - y_2)(\cos\beta_1 - \cos\theta\cos\beta_2) + (z - z_2)(\cos\gamma_1 - \cos\theta\cos\gamma_2) = 0. \quad (13)$$

Now solve simultaneously for x, y, and z, equations (10), (12), and (13); and similarly solve equations (11), (12), and (13). Call the first set of coördinates so obtained, (x_3, y_3, z_3), and the second set (x_4, y_4, z_4). The desired coördinates are as follows.

$$x_3 = \frac{\begin{vmatrix} 0 & \cos\gamma_1\cos\alpha_2 - \cos\gamma_2\cos\alpha_1 & \cos\alpha_1\cos\beta_2 - \cos\alpha_2\cos\beta_1 \\ 0 & \cos\beta_2 - \cos\theta\cos\beta_1 & \cos\gamma_2 - \cos\theta\cos\gamma_1 \\ k_3 & \cos\beta_1 - \cos\theta\cos\beta_2 & \cos\gamma_1 - \cos\theta\cos\gamma_2 \end{vmatrix}}{\begin{vmatrix} \cos\beta_1\cos\gamma_2 - \cos\beta_2\cos\gamma_1 & \cos\gamma_1\cos\alpha_2 - \cos\gamma_2\cos\alpha_1 & \cos\alpha_1\cos\beta_2 - \cos\alpha_2\cos\beta_1 \\ \cos\alpha_2 - \cos\theta\cos\alpha_1 & \cos\beta_2 - \cos\theta\cos\beta_1 & \cos\gamma_2 - \cos\theta\cos\gamma_1 \\ \cos\alpha_1 - \cos\theta\cos\alpha_2 & \cos\beta_1 - \cos\theta\cos\beta_2 & \cos\gamma_1 - \cos\theta\cos\gamma_2 \end{vmatrix}}$$

$$y_3 = \frac{\begin{vmatrix} \cos\beta_1\cos\gamma_2 - \cos\beta_2\cos\gamma_1 & 0 & \cos\alpha_1\cos\beta_2 - \cos\alpha_2\cos\beta_1 \\ \cos\alpha_2 - \cos\theta\cos\alpha_1 & 0 & \cos\gamma_2 - \cos\theta\cos\gamma_1 \\ \cos\alpha_1 - \cos\theta\cos\alpha_2 & k_3 & \cos\gamma_1 - \cos\theta\cos\gamma_2 \end{vmatrix}}{\Delta}$$

$$z_3 = \frac{\begin{vmatrix} \cos\beta_1\cos\gamma_2 - \cos\beta_2\cos\gamma_1 & \cos\gamma_1\cos\alpha_2 - \cos\gamma_2\cos\alpha_1 & 0 \\ \cos\alpha_2 - \cos\theta\cos\alpha_1 & \cos\beta_2 - \cos\theta\cos\beta_1 & 0 \\ \cos\alpha_1 - \cos\theta\cos\alpha_2 & \cos\beta_1 - \cos\theta\cos\beta_2 & k_3 \end{vmatrix}}{\Delta}$$

where

$$k_3 = y_2(\cos\beta_1 - \cos\theta\cos\beta_2) + z_2(\cos\gamma_1 - \cos\theta\cos\gamma_2).$$

Similarly we obtain:

$$x_4 = \frac{\begin{vmatrix} k_1 & \cos\gamma_1\cos\alpha_2 - \cos\gamma_2\cos\alpha_1 & \cos\alpha_1\cos\beta_2 - \cos\alpha_2\cos\beta_1 \\ 0 & \cos\beta_2 - \cos\theta\cos\beta_1 & \cos\gamma_2 - \cos\theta\cos\gamma_1 \\ k_3 & \cos\beta_1 - \cos\theta\cos\beta_2 & \cos\gamma_1 - \cos\theta\cos\gamma_2 \end{vmatrix}}{\Delta}$$

$$y_4 = \frac{\begin{vmatrix} \cos\beta_1\cos\gamma_2 - \cos\beta_2\cos\gamma_1 & k_1 & \cos\alpha_1\cos\beta_2 - \cos\alpha_2\cos\beta_1 \\ \cos\alpha_2 - \cos\theta\cos\alpha_1 & 0 & \cos\gamma_2 - \cos\theta\cos\gamma_1 \\ \cos\alpha_1 - \cos\theta\cos\alpha_2 & k_3 & \cos\gamma_1 - \cos\theta\cos\gamma_2 \end{vmatrix}}{\Delta}$$

$$z_4 = \frac{\begin{vmatrix} \cos\beta_1\cos\gamma_2 - \cos\beta_2\cos\gamma_1 & \cos\gamma_1\cos\alpha_2 - \cos\gamma_2\cos\alpha_1 & k_1 \\ \cos\alpha_2 - \cos\theta\cos\alpha_1 & \cos\beta_2 - \cos\theta\cos\beta_1 & 0 \\ \cos\alpha_1 - \cos\theta\cos\alpha_2 & \cos\beta_1 - \cos\theta\cos\beta_2 & k_3 \end{vmatrix}}{\Delta}$$

where

$$k_1 = y_2(\cos\gamma_1\cos\alpha_2 - \cos\gamma_2\cos\alpha_1) + z_2(\cos\alpha_1\cos\beta_2 - \cos\alpha_2\cos\beta_1)$$

and

$$k_3 = y_2(\cos\beta_1 - \cos\theta\cos\beta_2) + z_2(\cos\gamma_1 - \cos\theta\cos\gamma_2).$$

The stratigraphic thickness is now defined as $T = \overline{P_2P_4} - \overline{P_1P_3}$, where

$$P_1 = (0, 0, 0) \qquad P_2 = (0, y_2, z_2) \qquad P_3 = (x_3, y_3, z_3) \qquad P_4 = (x_4, y_4, z_4)$$

$$\overline{P_1P_3} = \sqrt{x_3^2 + y_3^2 + z_3^2}$$

$$\overline{P_2P_4} = \sqrt{x_4^2 + (y_4 - y_2)^2 + (z_4 - z_2)^2}.$$

PROBLEM

In order to obtain a comparable answer, a problem is solved that was earlier solved by the writer[8] in illustrating a different three-dimensional method.

Let the strike and dip of the bedding planes at stations P_1 and P_2 be, respectively, N. 35° E., 10° S.E., and N. 70° E., 50° S. Let the direction of the traverse be S. 5° E. the slope of the hillside be 5°, and the slope distance be 450 feet. And finally, let the direction of the dip be opposite to that of the hillside slope.

By using a coördinate system in which the positive end of the Y axis points S. 5° E., the coördinates of P_1 and P_2 may be written respectively as follows.

$$P_1 = (0, 0, 0) \quad \text{and} \quad P_2 = (0, 448.29, 39.22)$$

[8] J. B. Mertie, Jr., *op. cit.*, p. 1131.

From Figure 3, it is apparent that the solution of the four spherical quadrantal triangles gives the following.

$$\cos \alpha_1 = \sin 10^\circ \cos 40^\circ = .13302$$
$$\cos \alpha_2 = \sin 50^\circ \cos 75^\circ = .19827$$
$$\cos \beta_1 = \sin 10^\circ \cos 50^\circ = .11162$$
$$\cos \beta_2 = \sin 50^\circ \cos 15^\circ = .73993.$$

Also,

$$\cos \gamma_1 = \cos 10^\circ = .98481$$
$$\cos \gamma_2 = \cos 50^\circ = .64279.$$

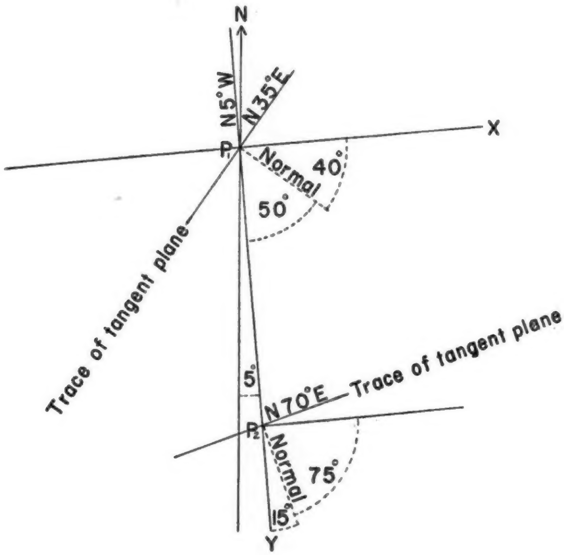


FIG. 3.—Structural data in XY plane, with Y axis drawn to coincide with direction of traverse.

Other data that are needed are the following.

$$\cos \alpha_1 \cos \beta_2 = .09843$$
$$\cos \alpha_1 \cos \gamma_2 = .08550$$
$$\cos \beta_1 \cos \alpha_2 = .02213$$
$$\cos \beta_1 \cos \gamma_2 = .07175$$

$$\begin{aligned}
\cos\gamma_1 \cos\alpha_2 &= .19526\\
\cos\gamma_1 \cos\beta_2 &= .72869\\
\cos\theta &= .74199\\
\cos\theta \quad \cos\alpha_1 &= .09870\\
\cos\theta \quad \cos\alpha_2 &= .14711\\
\cos\theta \quad \cos\beta_1 &= .08282\\
\cos\theta \quad \cos\beta_2 &= .54902\\
\cos\theta \quad \cos\gamma_1 &= .73072\\
\cos\theta \quad \cos\gamma_2 &= .47694
\end{aligned}$$

$$\begin{aligned}
k_1 &= [448.29(.19526 - .08550) + 39.22(.09843 - .02213)]\\
&= 49.204 + 2.992 = 52.196\\
k_3 &= [448.29(.11162 - .54902) + 39.22(.98481 - .47694)]\\
&= -196.08 + 19.92 = -176.16.
\end{aligned}$$

The coördinates of P_3 and P_4 are then found as follows.

$$x_3 = \frac{\begin{vmatrix} 0 & .10976 & .07630\\ 0 & .65711 & -.08793\\ -176.16 & -.43740 & .50787 \end{vmatrix}}{\begin{vmatrix} -.65694 & .10976 & .07630\\ .09957 & .65711 & -.08793\\ -.01409 & -.43740 & .50787 \end{vmatrix}} = -52.140$$

$$y_3 = \frac{\begin{vmatrix} -.65694 & 0 & .07630\\ .09957 & 0 & -.08793\\ -.01409 & -176.16 & .50787 \end{vmatrix}}{\Delta} = -43.749$$

$$z_3 = \frac{\begin{vmatrix} -.65694 & .10976 & 0\\ .09957 & .65711 & 0\\ -.01409 & -.43740 & -176.16 \end{vmatrix}}{\Delta} = -385.986$$

$$x_4 = \frac{\begin{vmatrix} 52.196 & .10976 & .07630\\ 0 & .65711 & -.08793\\ -176.16 & -.43740 & .50787 \end{vmatrix}}{\Delta} = -128.434$$

$$y_4 = \frac{\begin{vmatrix} -.65694 & 52.196 & .07630 \\ .09957 & 0 & -.08793 \\ -.01409 & -176.16 & .50787 \end{vmatrix}}{\Delta} = -31.003$$

$$z_4 = \frac{\begin{vmatrix} -.65694 & .10976 & 52.196 \\ .09957 & .65711 & 0 \\ -.01409 & -.43740 & -176.16 \end{vmatrix}}{\Delta} = -377.125$$

$$\overline{P_1P_3} = \sqrt{(-52.140)^2 + (-43.749)^2 + (-385.986)^2} = 391.94$$

$$\overline{P_2P_4} = \sqrt{(-128.434)^2 + (-479.293)^2 + (-416.345)^2} = 647.73$$

$$\overline{P_2P_4} - \overline{P_1P_3} = 647.73 - 391.94 = 255.79.$$

Stratigraphic thickness, $T = 256$ feet.

The length of the perpendicular connecting the two skew lines, as earlier stated, is a measure of the deviation of the stratigraphic surfaces from sphericity. This length is readily found, as follows.

$$\overline{P_3P_4} = \sqrt{(76.294)^2 + (-12.746)^2 + (-8.861)^2} = 77.86.$$

Compared with radii of 392 and 648 feet, 78 feet is a fairly large value, and indicates that the stratigraphic surfaces in this particular problem diverge markedly from sphericity.

COMPARISON OF METHODS

Reference has already been made to the oldest three-dimensional empirical method of computing stratigraphic thickness, wherein the mean strike and mean dip at two stations are used in any of several formulae that apply to a homoclinal sequence of rocks. Computed by this method, the stratigraphic thickness in the preceding problem is found to be 223 feet.

Another three-dimensional empirical method, devised by the writer,[9] may be called the method of mean trigonometric functions. This resembles the preceding method in that homoclinal formulae are utilized; but it differs in that mean values of the trigonometric functions, based on the assumption of circular arc variations in strike and dip, are substituted in the homoclinal formulae, instead of the corresponding functions of mean strike and mean dip. Computed by this method, the stratigraphic thickness is found to be 243 feet.

By the method demonstrated in this paper, the stratigraphic thickness is found to be 256 feet. It is probable that this is a closer approximation to the true thickness than the other two values; yet all three of them are obtained from

[9] J. B. Mertie, Jr., *op. cit.*, pp. 1125–32.

empirical methods, so that no one can be taken as an absolute standard, for demonstrating errors in the other two. The value found by the method given in this paper, however, is 15 per cent greater than that found by the first method, but is only 5 per cent greater than that found by the second method. These results suggest, at least, that the stratigraphic thickness obtained in this problem by the first, or oldest, method is too small; and, while the impracticability of the third method is admitted for general application, it is also suggested that the second method, an altogether practical one, is likely to give a closer approximation to the true thickness than the first one.

The lack of adequate data on the curvature of most folds, and the practical difficulties in evaluating such data, even when they are available, are responsible for the discrepancies previously cited. But this is only one of several intangible factors that may exist in the computation of stratigraphic thickness in parallel folds. Stratigraphic surfaces in competent beds are seldom strictly parallel; original variations may have existed in the thickness of the sediments, even within short distances; and accurate observations of strike and dip are difficult to obtain on isolated exposures. The field geologist hopes that some of these variable factors may be compensatory, but he also realizes that some of them may be additive, so that large errors can result in computing thickness in strongly folded competent beds. Probably, in such structures, the best that can be hoped for is an answer that is accurate to within 10 per cent, though in gentle folding, a higher degree of accuracy should be obtained.

None of these facts, however, is any argument against the use of precision methods in computing stratigraphic thickness, depth, or distance to a stratum, or other stratigraphic desiderata. Unavoidable errors are admitted always to be present, but such errors do not warrant the application of methods of computation that add additional errors. On the other hand, highly involved or laborious methods of computation can not be justified, except in special applications, or in the establishment of standards of comparison. The method presented in this paper falls in the latter category.

DIAMOND-DRILL CORE FROM BOURBON HIGH, CRAWFORD COUNTY, MISSOURI[1]

JAMES S. CULLISON AND SAMUEL P. ELLISON, JR.[2]
Rolla, Missouri

In March, 1944, the United States Bureau of Mines completed a diamond drill hole near the town of Bourbon in Crawford County, Missouri, at a depth of 1,824

[1] Published with the permission of the director of the Geological Survey of the United States Department of the Interior. Manuscript received, June 26, 1944.

[2] United States Geological Survey.

feet.[3] The hole was drilled vertically and its angle was measured at 400, 800, 1,200, and 1,600 feet. The hole passed through nearly 1,500 feet of Lower Ordovician and Upper Cambrian sediments before entering pre-Cambrian rhyolite. Core recovery was excellent and it is believed that the stratigraphic information obtained is of sufficient interest to justify the presentation of a detailed log. The Missouri Geological Survey and Water Resources coöperated fully in the study. Cuttings from the city of Bourbon well were made available for examination and during drilling operations many helpful consultations were held with John Grohskopf. The core has been given to the Missouri School of Mines and will be placed on permanent display in the geological department.

METHODS OF STUDY

All the core of sedimentary rock (0–1,482 feet) was split longitudinally with a Longyear core splitter. One-half of the core was retained for megascopic inspection and the other half was sacked in 5-foot units and ground to 6 mesh. A 20-cubic centimeter vial of each sample was given McQueen's treatment[4] to obtain insoluble residues. The record of the sedimentary rocks is in three forms: (1) half of the original core, (2) ground and sacked samples of 5-foot units, (3) insoluble residues of these units.

The determination of features such as color, bedding, stylolites, fossils, and general composition was made from a megascopic study of the uncrushed split core. Grain size was determined by examination of the ground samples under a wide-field binocular microscope. The character of the insoluble residues was studied under the microscope.

The igneous rock (1,482–1,824 feet) of the core was left intact, but thin sections were made at several depths.

In the pages which follow, the record of the core is shown graphically in two columns near the center of each page. The character of the original core and the volumetric percentages of insoluble residues are shown in the left column, the percentages of the various constituents of each residue are plotted in the right column. The width of each column represents 100 per cent.

Most of the color terms used are those of the Maerz and Paul color dictionary.[5]

A micrometer eye piece on the binocular microscope was used in determining grain size. Wentworth's definition of size grades is followed.[6] The Wentworth

[3] The hole was put down to test the Bourbon "high," the most striking magnetic anomaly known in the state. The anomaly was discovered and mapped by the Missouri Bureau of Geology and Mines in 1932 (Appendix IV, *57th Biennial Report*, 1933). As shown on the accompanying log, small amounts of iron were found.

[4] H. S. McQueen, "Insoluble Residues as a Guide in Stratigraphic Studies," *Missouri Bur. Geol. and Mines Bien. Rept. to 56th Assembly* (1901), appendix 1, pp. 102–31.

[5] A. Maerz and M. R. Paul, *A Color Dictionary*. McGraw-Hill Book Company, New York (1930).

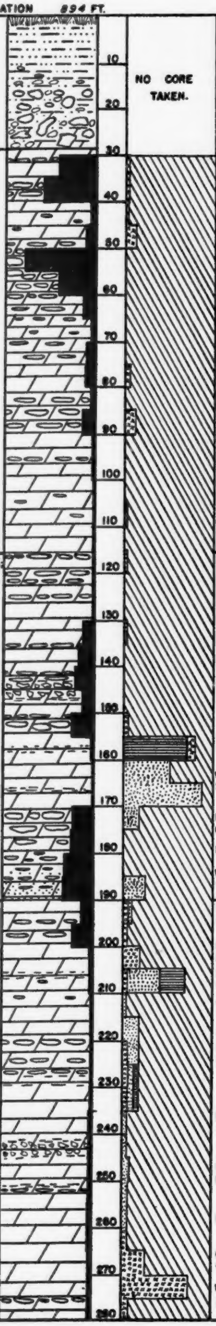
[6] C. K. Wentworth, "Grade and Class Terms for Clastic Sediments," *Jour. Geol.* Vol. 30 (1922), pp. 377–92.

BOURBON HIGH DIAMOND DRILL CORE

SEC. 3, T. 39N., R. 3W., CRAWFORD COUNTY, MISSOURI. DRILLED BY: U. S. BUREAU OF MINES

ORIGINAL CORE — ELEVATION 894 FT. — INSOLUBLE RESIDUE

EXPLANATION: TOTAL INSOLUBLE; CHERT; QUARTZ CRYSTALS; SHALE; SILTSTONE; SANDSTONE; ACCESSORIES



ORIGINAL CORE

SOIL, RESIDUAL CLAY, BROKEN DOLOMITE AND CHERT.

LOWER ORDOVICIAN

GASCONADE DOLOMITE 88 FT.

- LIGHT BUFF, COARSE-GRAINED DOLOMITE; WHITE AND GRAY, CHALKY, MASSIVE, BANDED CHERT; CALCITE AND QUARTZ GEODES; STYLOLITES.
- LIGHT BUFF, COARSE-GRAINED DOLOMITE; WHITE AND GRAY, CHALKY, BANDED CHERT AND CHERT BRECCIA.
- LIGHT BUFF, FINE-GRAINED DOLOMITE; WHITE AND GRAY, CHALKY, BANDED CHERT AND CHERT BRECCIA.
- LIGHT BUFF, POROUS, MASSIVE, COARSE-GRAINED DOLOMITE; WHITE AND GRAY CHERT; GREENISH-GRAY SHALE.
- LIGHT BUFF, POROUS, MASSIVE, SACCHAROIDAL, COARSE-GRAINED DOLOMITE; WHITE AND DARK GRAY CHERT AND CHERT BRECCIA.
- LIGHT GRAY AND BUFF, POROUS, SACCHAROIDAL, COARSE-GRAINED DOLOMITE; WHITE AND GRAY CHERT; STYLOLITES.

VAN BUREN DOLOMITE 74 FT.

- LIGHT GRAY AND BUFF, MASSIVE, COARSE-GRAINED DOLOMITE; WHITE AND GRAY, CHALKY, BANDED, OÖLITIC CHERT; GREENISH-GRAY SHALE.
- LIGHT GRAY, COARSE-GRAINED DOLOMITE; WHITE, MASSIVE, BANDED CHERT.
- LIGHT GRAY AND BUFF, COARSE-GRAINED DOLOMITE; WHITE, MASSIVE, OÖLITIC, BRECCIATED CHERT; CALCITE GEODES.
- LIGHT GRAY, MASSIVE, COARSE-GRAINED DOLOMITE; CALCITE GEODES; GREENISH-GRAY SHALE.
- LIGHT GRAY AND BUFF, MASSIVE, OÖLITIC DOLOMITE;
- WHITE, MASSIVE CHERT WITH SHRINKAGE CRACKS.
- DARK GRAY AND BUFF, MASSIVE, COARSE-GRAINED DOLOMITE; WHITE CHALKY CHERT.
- *GUNTER SANDSTONE MEMBER* WHITE SAND; GREEN SHALE; DOLOMITE.

UPPER CAMBRIAN

EMINENCE DOLOMITE TOTAL 124 FT.

- LIGHT BUFF, CAVERNOUS, COARSE-GRAINED DOLOMITE; WHITE, CHALKY CHERT; GREEN SHALE.
- LIGHT BUFF, CAVERNOUS, COARSE-GRAINED DOLOMITE; STYLOLITES; GREEN SHALE.
- LIGHT GRAY, CAVERNOUS, COARSE-GRAINED DOLOMITE; WHITE AND GRAY, OÖLITIC CHERT.
- LIGHT GRAY, CAVERNOUS, COARSE-GRAINED DOLOMITE; LIGHT AND DARK GRAY, BRECCIATED CHERT; GREEN SHALE.
- LIGHT GRAY, CAVERNOUS, COARSE-GRAINED DOLOMITE; STYLOLITES; VERY DARK GRAY CHERT NODULES.

INSOLUBLE RESIDUE

- DULL WHITE, MASSIVE, DENSE, GRANULAR CHERT; QUARTZ DRUSE.
- BRECCIATED, GRANULAR CHERT; QUARTZ DRUSE.
- BROWNISH-GRAY, MASSIVE, OÖLITIC CHERT; DULL WHITE, MASSIVE, FINELY DOLOCASTIC CHERT.
- GRAY, MASSIVE, DENSE, OÖLITIC, GRANULAR CHERT; DULL WHITE, DOLOCASTIC CHERT; QUARTZ CRYSTALS; LIGHT GREEN SHALE.
- BROWNISH-GRAY, MASSIVE, POROUS, FINELY GRANULAR CHERT; WHITE AND GRAY, OPAQUE CHERT; QUARTZ CRYSTALS.
- GRAY, GRANULAR CHERT; FRAGILE, WHITE, DOLOCASTIC CHERT.
- WHITE, GRANULAR CHERT.
- WHITE, MASSIVE, DENSE, OÖLITIC CHERT.
- DULL WHITE OPAQUE AND VITREOUS WHITE, POROUS, OÖLITIC CHERT; FINE QUARTZ CRYSTALS.
- LIGHT GRAY, MASSIVE, VITREOUS CHERT; DULL GREENISH-WHITE, FINELY DOLOCASTIC CHERT.
- WHITE, MASSIVE, DENSE, DOLOCASTIC CHERT; WHITE, SPONGY, OOCASTIC CHERT; GREEN SHALE.
- DULL WHITE, DENSE, OÖLITIC CHERT; WHITE POROUS CHERT; BROWNISH-GRAY, OÖLITIC CHERT; QUARTZ CRYSTALS.
- DULL WHITE, DOLOCASTIC, GRANULAR CHERT; GREEN SHALE.
- WHITE, POROUS CHERT; FINE, ROUND QUARTZ SAND.
- DULL WHITE, MASSIVE, COARSELY DOLOCASTIC, OÖLITIC AND OÖCASTIC CHERT; QUARTZ SAND.
- LIGHT TAN, FINELY GRANULAR CHERT.
- WHITE, MASSIVE, FINELY DOLOCASTIC CHERT; WHITE, FINE SAND AGGREGATES.
- DULL WHITE, POROUS CHERT; FINE SAND; QUARTZ CRYSTALS.
- BROWNISH-GRAY VITREOUS GRANULAR CHERT; DULL WHITE MASSIVE CHERT; QUARTZ CRYSTALS; ROUND QUARTZ SAND; LIMONITE; PYRITE; GREEN SHALE; GLAUCONITE.
- WHITE, DOLOCASTIC, FINE GRANULAR CHERT.
- BROWNISH-GRAY, MASSIVE, GRANULAR CHERT; FINE QUARTZ SAND AGGREGATES; GREEN, WAXY, DOLOCASTIC SHALE.
- BROWNISH-GRAY, POROUS, MASSIVE, GRANULAR CHERT; QUARTZ SAND.
- BROWNISH-GRAY, DENSE, GRANULAR CHERT; BROWNISH-GRAY, POROUS CHERT; QUARTZ SAND.
- BROWN AND WHITE, POROUS, GRANULAR CHERT.
- GRAY, GREASY, MASSIVE, GRANULAR CHERT; QUARTZ DRUSE.
- WHITE AND BROWN, MASSIVE, GRANULAR CHERT; FINE GRANULAR QUARTZ.

BOURBON HIGH DIAMOND DRILL CORE (CONT.)

UPPER CAMBRIAN

ORIGINAL CORE

EMINENCE DOLOMITE

LIGHT GRAY, CAVERNOUS, COARSE-GRAINED DOLOMITE; GRAYISH-GREEN SHALE.

BUFF AND GRAY COARSE-GRAINED DOLOMITE; WHITE CHERT; QUARTZ DRUSE.

POTOSI DOLOMITE TOTAL 397 FT.

LIGHT GRAY AND BUFF, CAVERNOUS, MEDIUM-GRAINED DOLOMITE; DARK GRAY, VITREOUS, BRECCIATED, OÖLITIC CHERT; QUARTZ DRUSE.

ABUNDANT QUARTZ DRUSE.

LIGHT GRAY AND BUFF, MEDIUM-GRAINED DOLOMITE.

ABUNDANT QUARTZ DRUSE.

MEDIUM TAN, MEDIUM-GRAINED DOLOMITE; GRAY AND BUFF, VITREOUS, GRANULAR CHERT; QUARTZ DRUSE.

GRAY AND BUFF GRANULAR CHERT.

DEEP TAN, MEDIUM AND COARSE-GRAINED DOLOMITE; ABUNDANT QUARTZ DRUSE.

GRAYSTONE GRAY, MEDIUM AND COARSE-GRAINED DOLOMITE; ABUNDANT QUARTZ DRUSE.

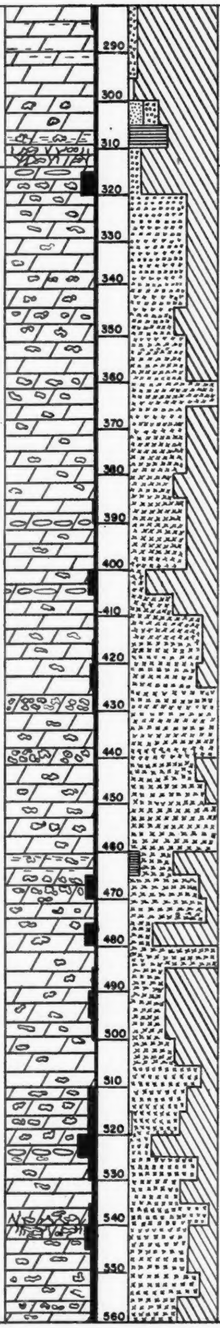
ABUNDANT QUARTZ DRUSE.

GRAYSTONE GRAY, MEDIUM AND COARSE-GRAINED DOLOMITE; ABUNDANT QUARTZ DRUSE.

GRAYSTONE GRAY, MEDIUM AND COARSE-GRAINED DOLOMITE; COARSELY OÖLITIC CHERT; BROWN QUARTZ DRUSE.

ABUNDANT QUARTZ DRUSE; CALCITE VEINS.

BROWN QUARTZ DRUSE



INSOLUBLE RESIDUE

WHITE, VITREOUS, POROUS, GRANULAR CHERT; QUARTZ DRUSE.

WHITE, DENSE, FINELY OÖLITIC CHERT; WHITE POROUS GRANULAR CHERT; QUARTZ CRYSTALS; PYRITE.

WHITE, GRAY AND BROWN, POROUS, GRANULAR CHERT; QUARTZ SAND; QUARTZ CRYSTALS; GREEN SHALE.

DULL WHITE, DENSE, MASSIVE CHERT; LIGHT GRAY GRANULAR CHERT; QUARTZ DRUSE.

WHITE, COARSELY DOLOCASTIC CHERT; FINELY GRANULAR QUARTZ AGGREGATES.

BANDED QUARTZ DRUSE WITH BOTRYOIDAL AND DOLOCASTIC SURFACES.

BANDED QUARTZ DRUSE WITH BOTRYOIDAL AND DOLOCASTIC SURFACES.

FINELY GRANULAR QUARTZ AGGREGATES.

BANDED QUARTZ DRUSE WITH BOTRYOIDAL AND DOLOCASTIC SURFACES.

WHITE, COARSELY GRANULAR CHERT; GREEN CHERT; BANDED QUARTZ DRUSE.

WHITE, FINELY GRANULAR QUARTZ AGGREGATES; BANDED QUARTZ DRUSE WITH BOTRYOIDAL AND DOLOCASTIC SURFACES.

QUARTZ CRYSTALS; FINELY GRANULAR QUARTZ AGGREGATES.

QUARTZ CRYSTALS; BROWN, COARSELY DOLOCASTIC CHERT.

BUFF, GRANULAR QUARTZ AGGREGATES.

BUFF, GRANULAR DOLOCASTIC CHERT; GRANULAR QUARTZ AGGREGATES; BROWNISH-GREEN SHALE.

WHITE AND BUFF, BANDED, DOLOCASTIC, GRANULAR CHERT; QUARTZ DRUSE.

BROWN, GRANULAR, COARSELY DOLOCASTIC CHERT; QUARTZ DRUSE.

WHITE AND BROWN, GRANULAR, DOLOCASTIC CHERT; QUARTZ DRUSE; PYRITE.

WHITE AND BROWN, DOLOCASTIC, COARSELY OÖLITIC AND OÖCASTIC, GRANULAR CHERT. QUARTZ DRUSE.

BROWN, DOLOCASTIC, GRANULAR CHERT; QUARTZ DRUSE.

BROWN, DOLOCASTIC, GRANULAR CHERT; BANDED QUARTZ DRUSE.

BOURBON HIGH DIAMOND DRILL CORE (CONT.)

UPPER CAMBRIAN

ORIGINAL CORE

POTOSI DOLOMITE — TOTAL 397 FT.

GRAYSTONE GRAY, MEDIUM AND COARSE-GRAINED DOLOMITE; BROWN QUARTZ DRUSE; CALCITE DRUSE.

DARK BUFF, MEDIUM AND COARSE-GRAINED DOLOMITE; QUARTZ DRUSE; CALCITE CRYSTALS.

DARK BUFF, MEDIUM AND COARSE-GRAINED DOLOMITE; QUARTZ DRUSE.

DARK BUFF, FINE AND MEDIUM-GRAINED DOLOMITE; STYLOLITES; QUARTZ DRUSE.

DARK BUFF, FINE AND MEDIUM-GRAINED, CAVERNOUS DOLOMITE; CALCITE VEINS; QUARTZ DRUSE; GREEN SHALE.

DARK BUFF, MEDIUM AND COARSE-GRAINED, CAVERNOUS DOLOMITE; QUARTZ DRUSE; DOLOMITE PEBBLE CONGLOMERATE

DERBY AND DOE RUN DOLOMITES — 108 FT.

DARK GRAY, FINE AND MEDIUM-GRAINED, CAVERNOUS DOLOMITE; STYLOLITES; GRAY SHALE.

DULL, DRAB GRAY, FINE-GRAINED, STYLOLITIC DOLOMITE; GREENISH-GRAY SHALE.

LIGHT GRAY, FINE-GRAINED, CAVERNOUS DOLOMITE; CALCITE DRUSE.

DARK GRAY, CAVERNOUS, RECRYSTALLIZED MEDIUM-GRAINED DOLOMITE; GREEN SHALE.

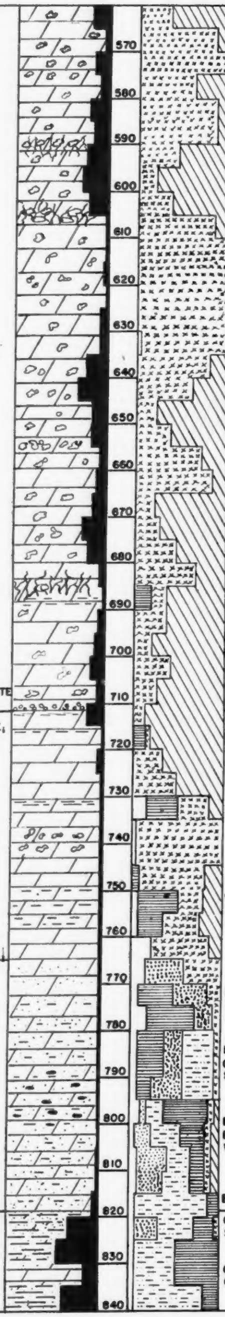
CORE SIZE 2⅛ / 1⅜

LIGHT GRAY, CAVERNOUS, RECRYSTALLIZED, THIN-BEDDED, STYLOLITIC, FINE-GRAINED DOLOMITE; PYRITE LENSES.

DARK GRAY, CAVERNOUS, RECRYSTALLIZED, THIN-BEDDED, STYLOLITIC, FINE-GRAINED DOLOMITE; DARK GRAY, THIN-BEDDED SHALE.

DAVIS FORMATION

GREENISH-GRAY, THIN-BEDDED, MICACEOUS SHALE AND SILTSTONE; DARK GRAY, THIN-BEDDED, STYLOLITIC, MEDIUM-GRAINED DOLOMITE.



INSOLUBLE RESIDUE

LIGHT BROWN, DOLOCASTIC, GRANULAR CHERT; BANDED QUARTZ DRUSE.

LIGHT BROWN, DOLOCASTIC, GRANULAR CHERT; BANDED QUARTZ DRUSE WITH BOTRYOIDAL AND DOLOCASTIC SURFACES.

LIGHT BROWN, DOLOCASTIC, GRANULAR CHERT; QUARTZ CRYSTALS; PYRITE; RHYOLITE.

BANDED QUARTZ DRUSE WITH BOTRYOIDAL AND DOLOCASTIC SURFACES.

BANDED QUARTZ DRUSE; MAGNETITE AND BARITE.

LIGHT BROWN, DOLOCASTIC, GRANULAR CHERT; BANDED QUARTZ DRUSE.

BROWN AND TAN, DOLOCASTIC, GRANULAR CHERT; BANDED QUARTZ DRUSE.

DULL WHITE AND TAN, DOLOCASTIC, GRANULAR CHERT; GREEN SHALE; QUARTZ CRYSTALS.

WHITE AND BROWN, DOLOCASTIC, GRANULAR CHERT; QUARTZ DRUSE.

DULL WHITE, FINELY DOLOCASTIC CHERT; QUARTZ DRUSE; GREEN SHALE; LIMONITE.

WHITE AND BROWN, DOLOCASTIC, GRANULAR CHERT; GREEN SHALE; QUARTZ CRYSTALS; PYRITE AND LIMONITE.

WHITE QUARTZ AGGREGATES; SPONGY PYRITE.

WHITE GRANULAR DOLOCASTIC CHERT; GREEN SHALE; QUARTZ AGGREGATES; RHYOLITE, HEMATITE, AND MAGNETITE.

FINE WHITE SAND; BROWN QUARTZ AGGREGATES; GREEN SHALE; PYRITE, HEMATITE, MAGNETITE, AND RHYOLITE.

DARK BROWN SILTSTONE; GREEN SHALE; GRANULAR QUARTZ AGGREGATES; PYRITE AND SPECULARITE; WHITE SAND.

BROWN AND WHITE, DOLOCASTIC CHERT; BROWN SILTSTONE; QUARTZ AGGREGATES; WHITE SANDSTONE; PYRITE.

BROWN SILTSTONE AND SHALE; PYRITE

GREENISH-GRAY SHALE; GRAY GLAUCONITIC SILTSTONE; FINE SAND; PYRITE.

GRAY GLAUCONITIC SILTSTONE; GREENISH-GRAY SHALE.

BOURBON HIGH DIAMOND DRILL CORE (CONT.)

UPPER CAMBRIAN

DAVIS FORMATION — TOTAL 206 FT.

ORIGINAL CORE

GREENISH-GRAY, THIN-BEDDED SHALE; GRAY, MEDIUM-GRAINED, STYLOLITIC DOLOMITE; EDGEWISE CONGLOMERATE.

GREENISH-GRAY, THIN-BEDDED SHALE AND SILTSTONE; GRAY, MEDIUM-GRAINED, STYLOLITIC DOLOMITE.

GREENISH-GRAY, THIN-BEDDED SHALE AND SILTSTONE; GRAY, MEDIUM-GRAINED, STYLOLITIC DOLOMITE.

GREENISH-GRAY, THIN-BEDDED, CROSS-BEDDED SHALE AND SILTSTONE; GRAY, MEDIUM-GRAINED DOLOMITE; EDGEWISE CONGLOMERATE.

GREENISH-GRAY, THIN-BEDDED, SHALE AND SILTSTONE; GRAY, MEDIUM-GRAINED DOLOMITE; EDGEWISE CONGLOMERATE; INARTICULATE BRACHIOPODS.

GREENISH-GRAY, THIN-BEDDED, SHALE AND SILTSTONE; GLAUCONITE; COARSE-GRAINED SANDSTONE; GRAY, MEDIUM-GRAINED DOLOMITE; RHYOLITE PEBBLES; EDGEWISE CONGLOMERATE; INARTICULATE BRACHIOPODS.

GREENISH-GRAY, THIN-BEDDED, SHALE; EDGEWISE CONGLOMERATE; INARTICULATE BRACHIOPODS.

LIGHT DRAB GRAY, THIN-BEDDED, DOLOMITIC SILTSTONE

LIGHT DRAB GRAY, THIN-BEDDED, DOLOMITIC SILTSTONE.

INSOLUBLE RESIDUE

GREENISH-GRAY, GLAUCONITIC SHALE AND SILTSTONE; PYRITE.

GRAY TO BROWN SHALE AND SILTSTONE; RHYOLITE.

GREENISH-GRAY SHALE AND SILTSTONE.

GREENISH-GRAY SHALE AND SILTSTONE; PYRITE; LIMONITE; HEMATITE; RHYOLITE.

GREENISH-GRAY SHALE AND SILTSTONE; RHYOLITE.

LIGHT GRAY, GLAUCONITIC, MEDIUM-GRAINED SAND; GRAY SHALE; PYRITE, HEMATITE, AND RHYOLITE.

GREENISH-GRAY SHALE AND SILTSTONE; RHYOLITE AND GLAUCONITE.

GRAY AND WHITE, DOLOCASTIC SILTSTONE; PYRITE.

BONNETERRE DOLOMITE — TOTAL 250 FT.

ORIGINAL CORE

LIGHT GRAY, GLAUCONITIC, COARSE-GRAINED DOLOMITIC LIMESTONE; VERTICAL AND HORIZONTAL STYLOLITES.

LIGHT GRAY, DENSE, MEDIUM-GRAINED, DOLOMITIC LIMESTONE; CALCITE VEINS; GLAUCONITE; STYLOLITES; TRILOBITES.

LIGHT GRAY, DENSE, MEDIUM-GRAINED, DOLOMITIC LIMESTONE; GLAUCONITE; STYLOLITES; TRILOBITES.

LIGHT GRAY, MOTTLED, FINE AND MEDIUM-GRAINED DOLOMITIC LIMESTONE; DOLOMITIC LIMESTONE CONGLOMERATE; GLAUCONITE.

INSOLUBLE RESIDUE

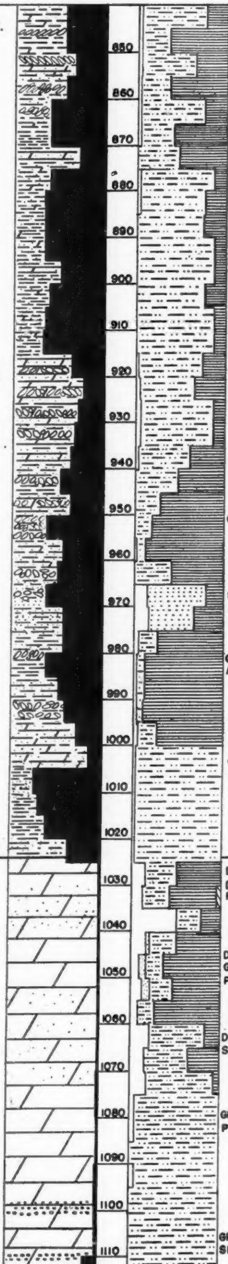
DARK, ORGANIC SHALE; GRAY AND BROWN, DOLOCASTIC SILTSTONE; GLAUCONITE AND PYRITE; BROWN CHERT.

DARK, ORGANIC SHALE; GRAY, SPONGY, GLAUCONITIC SILTSTONE; FINE-GRAINED SAND; PYRITE;

DARK, ORGANIC SHALE; SPONGY GLAUCONITIC SILTSTONE; RHYOLITE AND PYRITE.

GRAY, DOLOCASTIC, GLAUCONITIC SILTSTONE; PYRITE AND MAGNETITE.

GRAY AND BROWN, DOLOCASTIC, GLAUCONITIC SILTSTONE; PYRITE.



BOURBON HIGH DIAMOND DRILL CORE (CONT.)

UPPER CAMBRIAN

ORIGINAL CORE

BONNETERRE DOLOMITE TOTAL 250 FT.

GRAY, MOTTLED, FINE AND MEDIUM-GRAINED, DOLOMITIC LIMESTONE; GLAUCONITE; STYLOLITES.

LIGHT GRAY, MOTTLED, FINE AND MEDIUM-GRAINED, DOLOMITIC LIMESTONE, GRAY, IRREGULARLY BEDDED SHALE; COARSE-GRAINED GLAUCONITE; STYLOLITES.

LIGHT GRAY, MOTTLED, FINE AND MEDIUM-GRAINED, DOLOMITE; GRAY, IRREGULARLY BEDDED SHALE; COARSE-GRAINED GLAUCONITE; STYLOLITES.

LIGHT GRAY, COARSE-GRAINED DOLOMITE; OÖLITIC DOLOMITIC LIMESTONE; GLAUCONITE; GREEN SHALE; TRILOBITES.

LIGHT GRAY, FINE AND MEDIUM-GRAIN, OÖLITIC, DOLOMITIC LIMESTONE; GRAY, IRREGULARLY BEDDED SHALE; GLAUCONITE; VERTICAL AND HORIZONTAL STYLOLITES.

LIGHT GRAY, COARSE-GRAINED DOLOMITE; GRAY SILTSTONE; COARSE-GRAINED GLAUCONITE; STYLOLITES.

LIGHT GRAY, SANDY AND SILTY, COARSE-GRAINED DOLOMITE; ABUNDANT GLAUCONITE.

LAMOTTE SANDSTONE TOTAL 207 FT.

LIGHT GRAY, COARSE-GRAINED SANDSTONE.

LIGHT GRAY, COARSE-GRAINED SANDSTONE; VERY DARK GRAY AND GREEN SHALE; PYRITE.

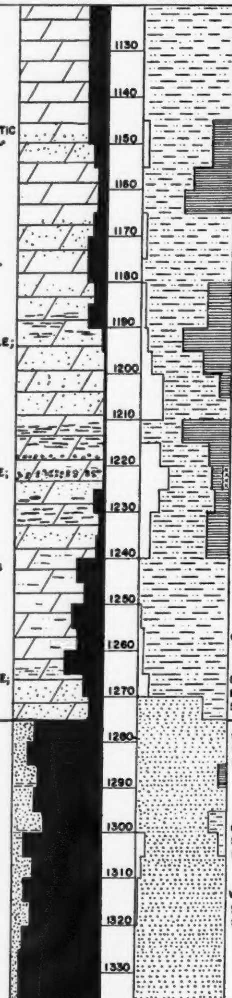
WHITE, SUBANGULAR, COARSE-GRAINED SANDSTONE.

WHITE, SUBANGULAR, COARSE-GRAINED SANDSTONE.

WHITE, MEDIUM-GRAINED SANDSTONE; RHYOLITE PEBBLES.

PINK, MEDIUM-GRAINED, SHALY SANDSTONE.

PINK AND TAN, MEDIUM-GRAINED SANDSTONE; RHYOLITE PEBBLES.



INSOLUBLE RESIDUE

GRAY AND BROWN DOLOCASTIC SILTSTONE; SOME GLAUCONITE.

BROWN, DOLOCASTIC SILTSTONE; GREEN SHALE; GLAUCONITE; PYRITE AND MAGNETITE.

GRAY, DOLOCASTIC SILTSTONE; GLAUCONITE AND PYRITE.

DARK, ORGANIC SHALE; GLAUCONITIC AND DOLOCASTIC SILTSTONE; PYRITE.

DARK, ORGANIC SHALE; GLAUCONITIC, OÖCASTIC AND DOLOCASTIC SILTSTONE; PYRITE AND LIMONITE.

DARK, ORGANIC SHALE; GLAUCONITIC, DOLOCASTIC SILTSTONE; OÖLITIC CHERT; QUARTZ CRYSTALS; PYRITE AND RHYOLITE.

GRAY GLAUCONITIC SILTSTONE; PYRITE.

GRAY GLAUCONITIC SILTSTONE; PYRITE.

GRAY GLAUCONITIC SILTSTONE; PYRITE AND RHYOLITE; WHITE, COARSE-GRAINED, ROUNDED SAND.

WHITE, COARSE-GRAINED, ROUNDED AND SUBANGULAR SAND; DARK, ORGANIC SHALE.

GRAY, COARSE-GRAINED, SUBANGULAR SAND; GREEN QUARTZ SAND; GRAY SILTSTONE; RHYOLITE.

WHITE, FINE TO COARSE-GRAINED, SUBANGULAR SAND; SILICEOUS CEMENT BETWEEN SOME SAND GRAINS.

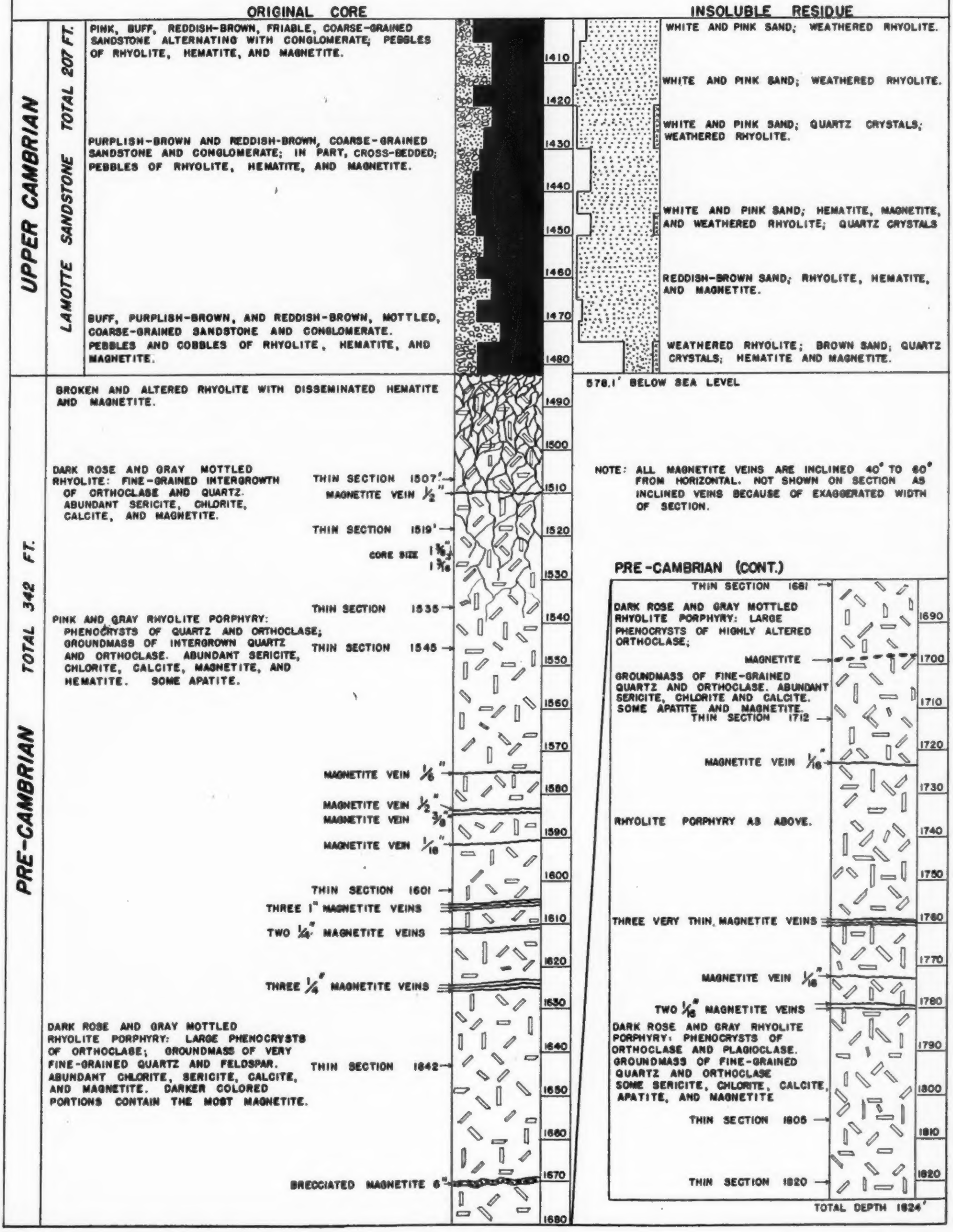
WHITE, FINE TO COARSE-GRAINED, SUBANGULAR SAND;

WHITE, FINE TO COARSE-GRAINED, ROUNDED SAND; RHYOLITE.

WHITE AND PINK, MEDIUM-GRAINED, ROUNDED SAND; GRAY SHALE; QUARTZ CRYSTALS.

WHITE AND PINK MEDIUM-GRAINED, SUBANGULAR SAND; WEATHERED RHYOLITE.

BOURBON HIGH DIAMOND DRILL CORE (CONT.)



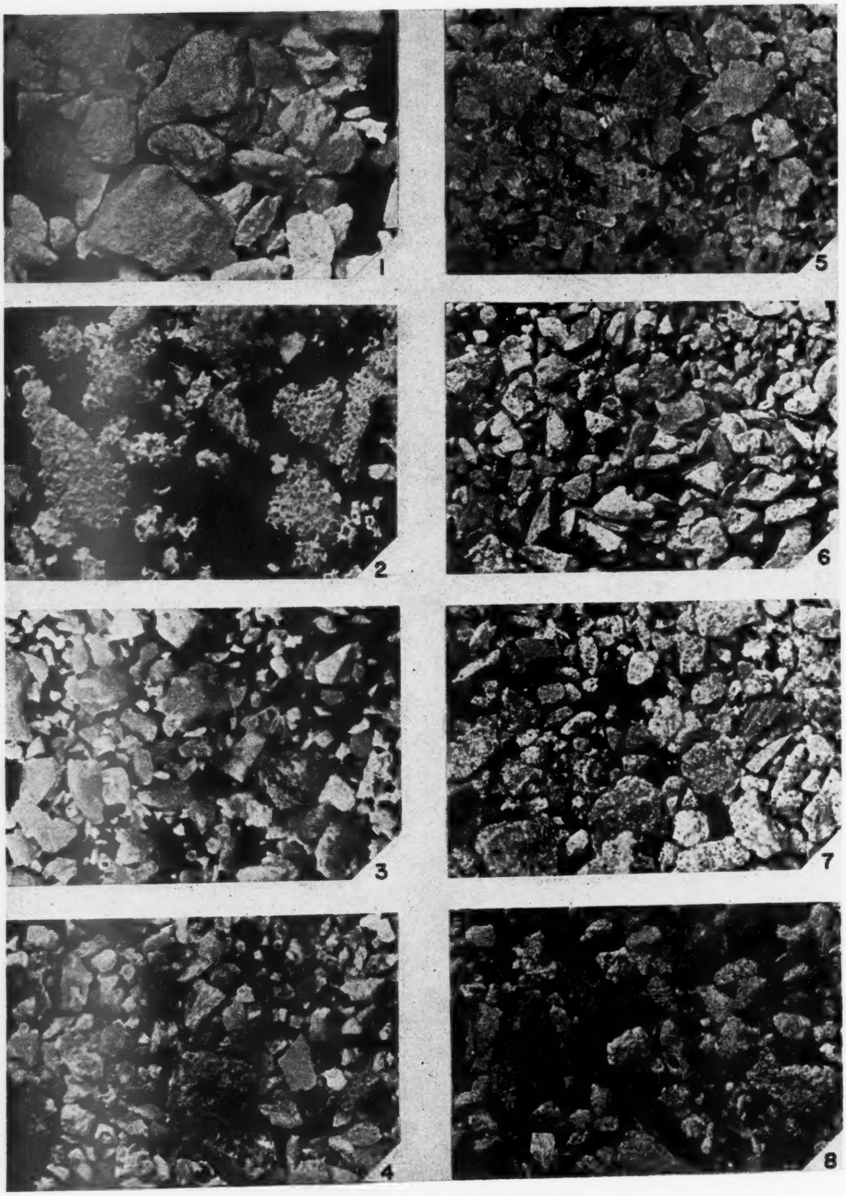


PLATE 1. (See opposite page for description)

scale was likewise applied to oölites, crystals of dolomite and limestone, dolocasts and oöcasts.

FORMATION BOUNDARIES

Typical residues of most of the formations are shown on Plate 1. The water-laid conglomerate at the base of the Lamotte sandstone contains interstitial sand grains that make it possible to recognize the boundary between the sedimentary section and the weathered rhyolite residuum that underlies it. The Lamotte-Bonneterre boundary falls within a zone of transition beds approximately 6 inches thick.

The base of the Davis formation is drawn at a depth of 1,024 feet on the basis of the amount and composition of the insoluble residues. This is the lowest point of a relatively large shale and siltstone percentage. Another possible place to delineate the base of the Davis formation is at the lower limit of the sandy and conglomeratic zone between depths of 965 and 975 feet. The final determination of this boundary should be guided by the results of faunal studies.

The base of the Derby-Doe Run sequence is placed immediately above the zone of typical shale and siltstone of the Davis. The beds above this boundary have less than 5 per cent total residue and those below average 35 per cent.

The base of the Potosi dolomite is not easily defined in this hole. However, it has been drawn at a dolomitic conglomerate horizon below the lowest occurrence of banded quartz druse. Beds below this horizon contain a very low percentage of insoluble material, but various constituents, including green shale, siltstone, fine quartz aggregates, and white dolocastic chert, are present.

The base of the Eminence dolomite is immediately above a dark gray, vitreous brecciated, oölitic chert. This is near the upper limit of banded quartz druse. Some quartz druse is present in the basal Eminence.

The base of the Van Buren formation is immediately below the sandy dolomitic phase called the Gunter sandstone member. Beds below this contain brownish gray granular chert; beds above it contain white massive coarsely dolocastic chert.

PLATE 1

FIG. 1.—Gasconade dolomite, depth 55–60 feet. Dull white, massive chert.

FIG. 2.—Van Buren formation, depth 175–180 feet. Dull white, massive coarsely dolocastic chert.

FIG. 3.—Eminence dolomite, depth 290–295 feet. White, dense, finely oölitic chert and white, porous granular chert.

FIG. 4.—Potosi dolomite, depth 520–525 feet. White and brown, dolocastic, coarsely oölitic and oöcastic, granular chert; quartz druse.

FIG. 5.—Potosi dolomite, depth 580–585 feet. Banded quartz druse and brown, dolocastic, granular chert.

FIG. 6.—Davis formation, depth 850–855 feet. Greenish gray, glauconitic shale and siltstone; pyrite.

FIG. 7.—Bonneterre dolomite, depth 1,220–1,225 feet. Dark, organic shale; glauconitic, dolocastic siltstone; oölitic chert; quartz crystals; pyrite and rhyolite.

FIG. 8.—Bonneterre dolomite, depth 1,125–1,130 feet. Gray and brown, dolocastic, glauconitic siltstone.

The base of the Gasconade dolomite is not easily defined and has been placed above the first occurrence of white vitreous oölitic chert. The dolomite above this boundary is saccharoidal and the chert is porous and granular. Below this the dolomite is less saccharoidal and the chert is vitreous.

DRILLING DATA

Drilled for: United States Bureau of Mines Project No. 940
Drilled by: E. J. Longyear Company
Land owner: Arthur Gross
Started: October 19, 1943
Completed: March 11, 1944
Location: 5,051 feet S. and 650 feet E. of NW. corner of Sec. 3, T. 39 N., R. 3 W., Crawford County, Missouri
Elevation: 894 feet
Total depth: 1,824 feet
Hole size:

Depth (*Feet*)	*Bit*	*Hole Diameter* (*Inches*)	*Core Diameter* (*Inches*)
0–30	Nx Casing	$1\frac{9}{16}$	$2\frac{3}{4}$
30–765	Nx	3	$2\frac{1}{8}$
765–1,524	Bx	$2\frac{3}{8}$	$1\frac{5}{8}$
1,524–1,824	Ax	$1\frac{7}{8}$	$1\frac{3}{16}$

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 9 (SEPTEMBER, 1944), PP. 1397-1398

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

RECENT PUBLICATIONS

ALASKA

*"Northern Alaska Good Prospecting," by Don L. Carroll. *Oil Weekly*, Vol. 114, No. 8 (Houston, July 24, 1944), pp. 66–67; map.

BRAZIL

**Geologia do Brasil*, by Avelino Ignacio de Oliveira and Othon Henry Leonardos. Second edition (1943). 813 pp., 37 pls. of fossils, 202 text figs., 112 photographs, 1 folded map of areal geology in colors. Approx. 6.25×9×2 inches. Servico de Informacao Agricola, Ministerio da Agricultura, Rio de Janeiro, Brasil. In Portuguese.

BOLIVIA

*"Generalized Geologic Map of Bolivia," by Victor Oppenheim. *Soc. Geol. Perú* (1944). Areal geology in colors. Sheet, 27×32.5 inches. Scale, 1–2,000,000. For sale by Sociedad Geologica del Perú, Apartado 2559, Lima, Peru. Price, $2.00.

CHINA

**Bibliography of Chinese Geology for the Years 1936–1940*, compiled by Y. S. Chi. *Natl. Geol. Survey China* (Pehpei, 1942). 147 pp.

*"Study on Certain Structural Features Occurring in the Central Region of Weiyuan Anticline, Szechuan," by H. H. Yao. *Bull. Geol. Soc. China*, Vol. 22, Nos. 3–4 (Pehpei, Chungking, Szechuan, December, 1942), pp. 227–39; 6 pls.

GENERAL

*"Electrical Well Logging," Pt. 1, by Hubert Guyod. *Oil Weekly*, Vol. 114, No. 10 (Houston, August 7, 1944), pp. 38–50; 1 fig., 2 tables.

KANSAS

*"Coal Resources of the Kansas City Group, Thayer Bed, in Eastern Kansas," by Walter H. Schoewe. *Kansas Geol. Survey Bull. 52*, Pt. 3 (Lawrence, July 25, 1944), pp. 85–136; 5 pls., 8 figs., 16 tables.

*"Exploration for Oil and Gas in Western Kansas during 1943," by Walter A. Ver Wiebe. *Ibid., Bull. 54* (July, 1944). 104 pp., 31 figs., 26 tables.

MONTANA

*"Montana's Newest Discovery of Particular Significance," by Eugene S. Perry. *Oil Weekly*, Vol. 114, No. 9 (Houston, July 31, 1944), pp. 34–37; 4 figs.

PENNSYLVANIA

*"Possible Future Oil Pools of Pennsylvania," by R. E. Sherrill. *Oil and Gas Jour.*, Vol. 43, No. 12 (Tulsa, July 29, 1944), pp. 129–30, 221–25; 1 map.

TENNESSEE

*"Possibilities for Oil and Gas in Tennessee," by Kendall E. Born. *Oil Weekly*, Vol. 114, No. 10 (Houston, August 7, 1944), pp. 54–58; stratigraphic chart, structural map, statistical table.

VENEZUELA

*"The Larger Foraminifera from San Juan de los Morros, State of Guarico, Venezuela," by C. M. Bramine Caudri. *Bulletins of Amer. Paleon.*, Vol. 28, No. 114 (July 16, 1944), pp. 351–404; 5 pls., 2 secs., 1 distribution chart. Paleontological Research Institution, Ithaca, New York. Price, $1.00.

WYOMING

*"Geologic Aspects of Wyoming and Outlook for Development," by Pierre La Fleiche. *Oil and Gas Jour.*, Vol. 43, No. 13 (Tulsa, August 5, 1944), pp. 38–42; 1 map.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Volume 18, No. 4 (July, 1944).

"Microfauna from the Carapita Formation of Venezuela," by E. S. Franklin

"Permian Trilobite Genera," by J. Marvin Weller

"Cretaceous Foraminifera from the Marlbrook Marl of Arkansas," by J. A. Cushman and W. H. Deaderick

"Smaller Foraminifera from the Porters Creek Formation (Paleocene) of Illinois," by Chalmer L. Cooper

"Lower Carboniferous Corals of the Genera *Rotiphyllum* and *Permia*," by R. G. S. Hudson

"Trilobite Genera *Goldius* and *Arctinurus* in the Silurian of Iowa and Illinois," by A. K. Miller and A. G. Unklesbay

"Eocene Foraminifera from Cape Blanco, Oregon," by O. L. Bandy

"Pendent Graptolites of Arkansas, Oklahoma, and Texas," by Charles E. Decker

"Bibliography and Index to New Genera, Species, and Varieties of Foraminifera for the Year 1941," by Hans E. Thalmann

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VOL. 28, NO. 9 (SEPTEMBER, 1944), PP. 1399-1412

THE ASSOCIATION ROUND TABLE

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L. R. McFarland	Gayle Scott	

COMMITTEE ON APPLICATIONS OF GEOLOGY

Paul Weaver (1947), *chairman*, Gulf Oil Corporation, Houston, Texas

1945	1946	1947
M. M. Leighton	R. M. Barnes	
	J. Brian Eby	
	H. S. McQueen	
	R. A. Steinmayer	

MEDAL AWARD COMMITTEE

A. Rodger Denison, *chairman* (1945), Amerada Petroleum Corporation, Tulsa, Oklahoma
Donald D. Hughes, *ex officio*, president of S.E.P.M.
William M. Rust, Jr., *ex officio*, president of S.E.G.

1945	1946	1947
G. Clark Gester	Frank R. Clark	H. B. Fuqua
Darsie A. Green	Raymond F. Baker	Thornton Davis
Wallace C. Thompson	James A. MacDonell	Hugh D. Miser

NATIONAL SERVICE COMMITTEE

Kenneth C. Heald, *chairman*, The Gulf Companies, Box 1166, Pittsburgh, Pennsylvania

Fritz L. Aurin	John O. Galloway	Edward A. Koester
A. E. Brainerd	M. Gordon Gulley	Morris M. Leighton
George M. Cunningham	W. Dow Hamm	Phil F. Martyn
Thornton Davis	Winthrop P. Haynes	Dean A. McGee
Ronald K. DeFord	W. B. Heroy	Clarence L. Moody
A. Rodger Denison	Harold W. Hoots	

DISTINGUISHED LECTURE COMMITTEE

JOHN L. FERGUSON, *chairman*, Amerada Petroleum Corporation, Tulsa, Oklahoma

JOHN W. INKSTER   W. J. HILSEWECK   FRED H. MOORE

COMMITTEE ON SOUTH AMERICAN GEOLOGY

A. I. LEVORSEN, *chairman*, 221 Woodward Boulevard, Tulsa, Oklahoma

COMMITTEE ON CODE OF ETHICS

C. W. TOMLINSON, *chairman*, 509 Simpson Building, Ardmore, Oklahoma

RAYMOND F. BAKER   ORVAL L. BRACE   HAROLD W. HOOTS   T. S. HARRISON

COMMITTEE ON METHOD OF ELECTION OF OFFICERS

JOHN G. BARTRAM, *chairman*, Stanolind Oil and Gas Company, Tulsa, Oklahoma

RONALD K. DEFORD   JOHN S. IVY   C. L. MOODY
W. DOW HAMM   HUGH D. MISER   EARL B. NOBLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

John Chapman Frye, Lawrence, Kan.
Wallace Lee, M. L. Thompson, Raymond C. Moore
Joseph Arthur Goodson, Clay City, Ill.
Darsie A. Green, Stewart Cronin, James G. Mitchell
John M. Kelly, Albuquerque, N. Mex.
Charles H. Rankin, Robert L. Bates, Frank E. Lewis
Oliver Thomas Lawhorn, Dallas, Tex.
Eugene McDermott, H. B. Peacock, Cecil H. Green
John Porter Lewis, Olney, Ill.
Kurt H. de Cousser, Rex P. Grant, George F. Yunck
James H. C. Martens, Morgantown, W. Va.
R. C. Tucker, David B. Reger, S. L. Galpin
David H. Swann, Urbana, Ill.
R. L. Belknap, P. Hastings Keller, T. S. Lovering
Virgil Willard Teufel, Dallas, Tex.
J. W. Hoover, G. W. Gulmon, H. B. Peacock

FOR ASSOCIATE MEMBERSHIP

Jane Titcomb Carlton, Washington, D. C.
M. M. Leighton, W. Dow Hamm, George V. Cohee
Thomas Stephens Gandy, San Antonio, Tex.
Robert N. Kolm, A. H. Alcorn, Van D. Robinson
Samuel Aubrey Kerr, Calgary, Alta., Canada
W. P. Hancock, S. E. Slipper, F. L. Fournier
Arthur Charles Lundahl, Chicago, Ill.
Louise Barton Freeman, W. C. Krumbein, Carey Croneis

Leo Emmett Swick, Jr., Mt. Vernon, Ill.
Fred H. Moore, Fred H. Wilcox, E. E. Rehn
Charles Hiram Williams, Houston, Tex.
Andrew Gilmour, Arland I. Innes, John L. Ferguson
Ruth Blanchard Wilson, Shreveport, La.
Henry J. Morgan, Jr., Clinton R. Stauffer, George H. Norton

FOR TRANSFER TO ACTIVE MEMBERSHIP

Willard Dickison Pye, Denver, Colo.
Carey Croneis, H. F. Moses, M. W. Fuller

SUPPLEMENTARY MEMBERSHIP LIST, SEPTEMBER 6, 1944

Members	102
Associates	78
Total additions since publication of list in March *Bulletin*	180

||Adams, Charles E., United Geophysical Co., 595 E. Colorado, Pasadena, Calif.
Addington, James William, Humble Oil & Refining Co., 202 Humble Bldg., Houston, Tex.
||Agnew, Allen Francis, U. S. Geological Survey, Box 261, Platteville, Wis.
Amstutz, Platte T., Jr., Standard Oil Co., 1755 Midland Bldg., Cleveland, Ohio
||Anderson, Keith Elliott, 1143 Fairview Ave., S. Pasadena, Calif.
Anderson, Richard S., consulting, c/o Anderson, Huffman, & Johnson, Box 1884, Midland, Tex.
||Anderson, Robert Edwin, 600 S. Ardmore Ave., Los Angeles, Calif.
Artman, George W., consulting, 120 E. Kirk St., Shawnee, Okla.
Atkinson, William H., independent, 3101 Apco Tower, Oklahoma City, Okla.
||Ballou, Albert Lorenzo, Seismograph Service Corp., 709 Kennedy Bldg., Tulsa, Okla.
Barrett, Lynn Wandell, Great Plains Oil & Gas Co., National Bank of Tulsa Bldg., Tulsa, Okla.
Barthelmes, Albert J., Seismograph Service Corp., 709 Kennedy Bldg., Tulsa, Okla.
Beard, Gordon Currie, Imperial Oil Co., Ltd., Box 330, Moose Jaw, Sask., Canada
Beck, August F., Cities Service Oil Co., Bartlesville, Okla.
Beckmann, Godfrey C., Standard Oil Co. of California, Box 392, Rio Vista, Calif.
Becwar, Harold David, The Texas Co., 1408 Alamo National Bldg., San Antonio, Tex.
Beel, Gordon Rutledge, Western Gulf Oil Co., Los Angeles, Calif.
Bickel, Harold Clayton, Tropical Oil Co., Apt. 335, Bogota, Colombia, S. A.
||Bird, Stuart Frederick, International Petroleum Co., Talara, Peru, S. A.
Bonifield, Henry Lease, Senora Oil & Gas Co., Box 198, Ada, Okla.
||Bradley, Henry Waring, Geochemical Surveys, Dallas, Tex.
||Brawner, John Douglas, The Texas Co., Denver, Colo.
Broadhurst, William L., U. S. Geological Survey, 302 W. Fifteenth St., Austin, Tex.
||Brooks, Tennant Julian, Norfolk Naval Hospital, Portsmouth, Va.
||Bryan, B. F., J. S. Abercrombie Co., Gulf Bldg., Houston, Tex.
Bryson, Robert P., U. S. Geological Survey, Box 1694, Little Rock, Ark.
Buckley, Stuart Edward, Humble Oil & Refining Co., Box 2180, Houston, Tex.
||Buckwalter, Tracy V., Jr., The Texas Co., Box 252, New Orleans, La.
||Burch, Earl Marvin, Stanolind Oil & Gas Co., 429 First National Bank Bldg., Wichita, Kans.
Burke, William Henry, Shell Oil Co., Inc., Box 1191, Tulsa, Okla.
Butcher, Walter William, Creole Petroleum Corp., Apt. 172, Maracaibo, Venezuela, S. A.
Carrey, Albert A., consulting, 529 E. Roosevelt Rd., Long Beach, Calif.
Choate, Bruce Murrow, The Atlantic Refining Co., Box 895, Lake Charles, La.
Clark, Samuel L., Jr., Royal Oil & Gas Corp., 307 Commercial National Bank Bldg., Shreveport, La.
Conant, Louis Cowles, U. S. Geological Survey, Box 2013, University, Ala.
Constant, Warren LeRoy, Amerada Petroleum Corp., Esperson Bldg., Houston, Tex.
||Coon, Maisie I., Humble Oil and Refining Co., Houston, Tex.
Copeland, Richard G., The Ohio Oil Co., Laurel, Miss.
Crockford, Michael Bertram Bray, California Standard Co., 700 Lancaster Bldg., Calgary, Alta., Canada
Crume, Robert Wilbur, The Texas Co., Box 2332, Houston, Tex.
||Current, Andrew Max, Carter Oil Co., Box 1490, Jackson, Miss.
Dally, Claude Franklin, consulting, 3724 Modlin, Fort Worth, Tex.
||Davis, Wesley Edward, The Texas Co., Box 405, Shelby, Mont.
Deegan, Charles J., Oil & Gas Journal, 211 S. Cheyenne, Tulsa, Okla.
Dickinson, Clyde Grant, Shell Oil Co., Inc., 2000 Alamo National Bldg., San Antonio, Tex.
||Doeringsfeld, Walter William, Jr., 416 N. Mason, Mishawaka, Ind.
||Dorbandt, Leslie Winston, The Atlantic Refining Co., Box 871, Midland, Tex.

Dorr, Clyde H., Jordan Petroleum Co., Oklahoma City, Okla.
||Douglass, Francis A., Jr., Argo Oil Corp., Box 1814, Midland, Tex.
Doyle, John Finley, Jr., Sun Oil Co., 832 Milam Bldg., San Antonio, Tex.
||Dudley, Ruth Mary, Shell Oil Co., Inc., Box 1191, Tulsa, Okla.
Dunlap, Albert D., Independent Exploration Co., 901 Esperson Bldg., Houston, Tex.
Edmunds, Frederic Harrison, University of Saskatchewan, Saskatoon, Sask., Canada
||Erdman, Oscar Alvin, Department of Mines & Resources, Geological Survey, Ottawa, Ont., Canada
Falkenhagen, Hodge Mobray, Independent Exploration Co., 901 Esperson Bldg., Houston, Tex.
Farrow, Benjamin Darwin, The Geotechnical Corp., 1702 Tower Petroleum Bldg., Dallas, Tex.
||Fee, Samuel Thomas, Shell Oil Co., Inc., Box 1155, Denton, Tex.
Fenwick, Willis Henry, Brown Geophysical Co., Box 319, Casper, Wyo.
Fillman, Louise, Shell Oil Co., Inc., Box 1509, Midland, Tex.
||Fox, Hamil Garland, Tidewater Seaboard Oil Co., Tyler, Tex.
Geis, Harold L., Barnsdall Oil Co., 2212 Esperson Bldg., Houston, Tex.
Gibson, Eugene Ashley, Humble Oil & Refining Co., 2316 American Bank Bldg., New Orleans, La.
||Gill, Robert J., Petroleum Administration for War, Washington, D. C.
Gorman, Joseph M., U. S. Geological Survey, Santa Rosa, N. Mex.
Gorton, Kenneth Arnold, General Petroleum Corp., Price, Utah
Graecen, Katherine Fielding, Shell Oil Co., Inc., Box 1509, Midland, Tex.
||Gray, William Ramsay, Geophysical Service, Inc., 1311 Republic Bank Bldg., Dallas, Tex.
Griffin, Judson Roy, The Texas Co., Box 262, Mt. Pleasant, Mich.
||Haas, Charles Frederick, The Chicago Corp., Box 1702, Corpus Christi, Tex.
||Hackel, Otto, Tidewater Associated Oil Co., Rt. 1, Box 197-X, Bakersfield, Calif.
||Hamilton, James Raymond, 2414 Barbee, Houston, Tex.
||Hannum, Robert Charles, Stanolind Oil & Gas Co., Box 961, Corsicana, Tex.
||Harman, Edward Coleman, Chapel Hill Gas System, 1610 Cotton Exchange Bldg., Dallas, Tex.
||Harris, David Vernon, Continental Oil Co., Denver, Colo.
||Harris, Stanley Edwards, Jr., State Geological Survey, Geology Annex, Iowa City, Iowa
Heminway, Caroline Ella, Shell Oil Co., Inc., 641 M. and M. Bldg., Houston, Tex.
Herrington, Louise Houssiere, The Texas Co., Box 2332, Houston, Tex.
Hinyard, Paul Brown, Shell Oil Co., Inc., 2000 Alamo National Bldg., San Antonio, Tex.
||Hoagland, R. Lloyd, c/o Kenneth A. Ellison, 736 N. E. Eighteenth St., Oklahoma City, Okla.
||Holmes, Clifford N., U. S. Geological Survey, Box 242, San Luis Obispo, Calif.
Horton, Claude Wendell, Underwater Sound Laboratory, Harvard University, Cambridge, Mass.
Houghton, Herbert Moore, Tidewater Associated Oil Co., Box 1404, Houston, Tex.
||Howard, Jesse James, Socony-Vacuum Oil Co., Valley Mills, Tex.
Hulin, Carlton D., Bacon Hall, University of California, Berkeley, Calif.
||Hurd, Harry Hathaway, 8445 San Gabriel Ave., South Gate, Calif.
||Jacobsen, C. Lynn, U. S. Geological Survey, Norman, Okla.
Johnson, Chester O., U. S. Geological Survey, Science Hall, University of Wyoming, Laramie, Wyo.
||Johnson, Floyd L., Honolulu Oil Corp., Kern County Land Bldg., Bakersfield, Calif.
Johnson, Lester Hayden, 608 S. Pennsylvania, Denver, Colo.
Keller, W. D., University of Missouri, 203 Swallow Hall, Columbia, Mo.
||Kelly, Elmo Lee, Stanolind Oil & Gas Co., Box 1099, Shawnee, Okla.
Kelly, Pennell Clarke, Superior Oil Co., 400 Oil & Gas Bldg., Houston, Tex.
Kerns, Floyd G., consulting, 2400 N. W. Nineteenth St., Oklahoma City, Okla.
Kirk, Charles T., 1226 S. Newport, Tulsa, Okla.
Krumholz, Alcuin John, Mene Grande Oil Co., Barcelona, Venezuela, S. A.
||Lackie, Opal Marie, Amerada Petroleum Corp., Los Angeles, Calif.
Lammers, Edward C. H., Standard Oil Co. of California, Standard Oil Bldg., Los Angeles, Calif.
||Langford, Eldon Woodward, Superior Oil Co., Seminole, Tex.
||Langford, Lucille E. T., Amerada Petroleum Corp., Seminole, Tex.
||Lebow, Ruth Young, U. S. Geological Survey, 533 U. S. Post Office Bldg., Los Angeles 12, Calif.
Liddell, Jessie K., Shell Oil Co., Inc., Box 901, San Antonio, Tex.
||Lines, Frederic G., California Standard Co., 700 Lancaster Bldg., Calgary, Alta., Canada
Loomis, Harve, Geo. P. Livermore, Inc., Lubbock, Tex.
Luttrell, Homer H., independent, Box 57, Effingham, Ill.
Marti, Ernest John, 1000 Westover, Norfolk, Va.
||Martin, Jack, General Geophysical Co., Box 547, Laurel, Miss.
McClure, Clair Edmond, Seismograph Service Corp., 709 Kennedy Bldg., Tulsa, Okla.
McCown, Clifton L., The Ohio Oil Co., Grand Rapids, Mich.
||McCullough, Joe Jackson, 1930 Bermuda St., Long Beach 4, Calif.
McDonald, Stanley Matthews, Louisiana Land & Exploration Co., Houma, La.
||McLaughlin, Kenneth Phelps, Stanolind Oil & Gas Co., 1132 Milam Bldg., San Antonio, Tex.
||McLennan, Lamar, Jr., Seaboard Oil Co. of Delaware, Box 152, Midland, Tex.
||Meents, Wayne Franklin, State Geological Survey, Urbana, Ill.
Melhorn, Ralph W., consulting, 720 N. Washington, Owasso, Mich.
Metz, Milam Sutton, Shell Oil Co., Inc., 2000 Alamo National Bldg., San Antonio, Tex.

Miller, Ralph LeRoy, U. S. Geological Survey, Washington, D. C.
Minshall, Francis Edward, Continental Oil Co., 601 W. Fifth St., Los Angeles, Calif.
Moneymaker, Berlen C., Tennessee Valley Authority, 510 A Union Bldg., Knoxville, Tenn.
||Montgomery, Porter A., Jr., Stanolind Oil & Gas Co., Box 2089, Amarillo, Tex.
Moore, Edward Lionel, Anglo-Ecuadorian Oilfields, Ltd., Casilla 410, Guayaquil, Ecuador, S. A.
||Morris, James Howard, U. S. Geological Survey, Box 2013, University, Ala.
Morrison, Robert E., Cities Service Oil Co., Box 2832, Odessa, Tex.
||Mumford, Clarence Scott, Shell Oil Co., Inc., Box 1191, Tulsa, Okla.
Murphy, Robert Emmett, Magnolia Petroleum Co., Albuquerque, N. Mex.
||Neal, Richard Freeman, Box 501, Cameron, W. Va.
Norman, M. E., consulting, 351 Edwards Hotel, Jackson, Miss.
||Normand, Spencer Raphael, Independent Exploration Co., 2210 Fort Worth National Bank Bldg., Fort Worth, Tex.
||Nowotny, Wilbur A., Stanolind Oil & Gas Co., Box 3092, Houston, Tex.
O'Brien, Decatur, Humble Oil & Refining Co., Box 72, Woodville, Tex.
||Oburn, Richard Charles, Box 1672, Wichita, Kans.
Ogier, Edwin Putman, c/o W. C. Spooner, Box 1195, Shreveport, La.
||Olson, Waynard George, Continental Oil Co., Denver, Colo.
||Parker, John Marchbank, Stanolind Oil & Gas Co., Box 40, Casper, Wyo.
Pettijohn, Francis J., Department of Geology, University of Chicago, Chicago, Ill.
Pfeffer, Guilford Clarence, Tidewater Associated Oil Co., Box Y, Los Nietos, Calif.
Porter, Charles W., Tidewater Associated Oil Co., Rt. 1, Box 197-X, Bakersfield, Calif.
Powell, Ezra H., Magnolia Petroleum Co., Box 1187, Beeville, Tex.
||Powell, Luther Clinton, The California Co., 1818 Canal Bldg., New Orleans, La.
Price, Edgar William, Stanolind Oil & Gas Co., Box 1092, Shreveport, La.
Priddy, Richard Randall, The Texas Co., Box 1073, Jackson, Miss.
Pryor, Mylert Frank, Black-Marshall Oil Co., Great Bend, Kans.
Putman, Darrell M., c/o T. H. McCasland, McCasland Bldg., Duncan, Okla.
Puzin, Lucien A., Schlumberger Well Surveying Corp., 1115 Hamilton Bldg., Wichita Falls, Tex.
||Rader, Harold E., Standard Oil Co. of California, 6042 W. Metropolitan Plaza, Los Angeles, Calif.
Raish, Henry Gustav, Stanolind Oil & Gas Co., Box 1540, Midland, Tex.
||Rangeler, Wallace William, Sun Oil Co., Box 3821, Beaumont, Tex.
Rice, Elmer M., Trowbridge Sample Service, Tyler, Tex.
Richards, Horace G., Academy of Natural Sciences, Nineteenth & Parkway, Philadelphia, Pa.
||Richardson, Eugene Stanley, Jr., Department of Geology, Princeton University, Princeton, N. J.
||Roberts, Thomas G., Shell Oil Co., Inc., Box 1191, Tulsa, Okla.
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Sanford, John Theron, Magnolia Petroleum Co., Box 1828, Oklahoma City, Okla.
Schmidt, Karl Henry, Arkansas Fuel Oil Co., Shreveport, La.
||Schulz, Lois Jane, Stanolind Oil & Gas Co., Box 1118, Tallahassee, Fla.
Scott, Erwin Ralph, Shell Oil Co., Inc., Box 32, Kilgore, Tex.
||Sheldon, Mary Elizabeth, Sun Oil Co., Milam Bldg., San Antonio, Tex.
||Shelton, Richard Cortez, 216 N. Oakhurst Dr., Beverly Hills, Calif.
||Siemon, Paul, 2000 Dracena, Bakersfield, Calif.
||Siever, Raymond, 5559 S. Drexel Ave., Chicago, Ill.
Smith, Edward James, Jr., Standard Oil Co. of Texas, Box 1249, Houston, Tex.
||Smith, Frederick James, Sinclair Wyoming Oil Co., Box 808, Evansville, Ind.
Spencer, Morris Grady, Las Tecas Petroleum Co., 406 Continental Bldg., Dallas, Tex.
Spivey, Robert Charles, Shell Oil Co., Inc., Box 1509, Midland, Tex.
||Springer, George Douglas, California Standard Co., 700 Lancaster Bldg., Calgary, Alta., Canada
||Stone, Benton, International Petroleum Co., Negritos, Peru, S. A.
Stow, Marcellus Henry, War Production Board, 1029 Temporary "R" Bldg., Washington, D. C.
Tixier, Maurice Pierre, Schlumberger Well Surveying Corp., 532 Wyoming National Bank Bldg., Casper, Wyo.
||Tourtelot, Harry Allison, Science Hall, University of Wyoming, Laramie, Wyo.
Townsend, Halstead Malkin, Superior Oil Co., Evansville, Ind.
||Von Eiff, Herbert Craft Whittington, Salt Dome Oil Corp., Mellie Esperson Bldg., Houston, Tex.
Waterbury, H. Paul, consulting, Box 122, Mt. Carmel, Ill.
Wheeler, Joseph Bowen, Stanolind Oil & Gas Co., Box 689, Jackson, Miss.
||White, Morris Barksdal, Sunray Oil Corp., Box 278, Allen, Okla.
Wilgus, Wallace LaFetra, Shell Oil Co., Inc., Box 2099, Houston, Tex.
||Williams, Edwin P., Shell Oil Co. of Canada, 116 Eighth Ave. W., Calgary, Alta., Canada
Willis, Vernon Howe, The Texas Co., Box 524, Corsicana, Tex.
||Wilsey, James Arthur, Jr., Carter Oil Co., Box 812, Lander, Wyo.
||Wilson, James Lee, 2207 Del Monte Dr., Houston, Tex.
||Wilson, Louita D., Geophysical Service, Inc., 1311 Republic Bank Bldg., Dallas, Tex.
||Zimmerman, John, Jr., Kaiser Corp., San Jose, Calif.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 9 (SEPTEMBER, 1944), PP. 1405-1412

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

CONSTITUTION[1]

ARTICLE I. NAME

This Association shall be called "The American Association of Petroleum Geologists," incorporated under the laws of Colorado.

ARTICLE II. OBJECT

The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and to encourage improvements in the methods of exploring for and exploiting these substances; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas.

ARTICLE III. MEMBERSHIP

Members

SECTION 1. Any person engaged in the work of petroleum geology or in research pertaining to petroleum geology or technology is eligible to active membership, provided he is a graduate of an institution of collegiate standing, in which institution he has done his major work in geology, or in sciences fundamental to petroleum geology, and in addition has had the equivalent of three years' experience in petroleum geology or in the application of these other sciences to petroleum geology or to research in petroleum geology or technology; and provided further that in the case of an applicant for membership who has not had the required collegiate or university training, but whose standing in the profession is well recognized, he shall be admitted to membership when his application shall have been favorably and unanimously acted upon by the executive committee; and provided further that these requirements shall not be construed to exclude teachers and research workers in recognized institutions, whose work is of such character as in the opinion of the executive committee shall qualify them for membership.

Active members alone shall be known as members.

Life Members

SECTION 2. The executive committee may grant life membership to members who have paid their dues and are otherwise qualified.

Associates

SECTION 3. Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, is eligible to associate membership, provided at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing, or shall be engaged in petroleum geology; and any person who is a graduate of an institution of collegiate standing in which he has done his major work in sciences fundamental to petroleum geology or petroleum technology, and who has the equivalent of one year's experience in the application of

[1] The constitution and by-laws were adopted 1918, and amended 1921, 1922, 1923, 1925, 1927, 1928, 1929, 1930, 1932, 1933, 1935, 1936, 1939, 1940, 1942, 1943, and 1944.

his science to the study of petroleum geology, shall be eligible to associate membership, provided at the time of his application for membership he shall be engaged in investigations in the broader subject of petroleum geology and technology.

Associate members shall be known as associates.

Associates shall enjoy all the privileges of membership in the Association, save that they shall not hold office, sign applications for membership, or vote; neither shall they have the privilege of advertising their affiliation with the Association in professional cards or professional reports or otherwise.

The executive committee may advance to active membership, without the formality of application for such change, those associates who have, subsequent to election, fulfilled the requirements for active membership.

Election to Membership

SECTION 4. Every candidate for admission as a member or associate shall submit a formal application on an application form authorized by the executive committee, signed by him, and endorsed by not less than three members who are in good standing, stating his training and experience and such other facts as the executive committee shall from time to time prescribe. Provided the executive committee, after due consideration, shall judge that the applicant's qualifications meet the requirements of the constitution, they shall cause to be published in the *Bulletin* the applicant's name and the names of his sponsors. If, after at least thirty days have elapsed since such publication, no reason is presented why the applicant should be not admitted, he shall be deemed eligible to membership or to associate membership, as the case may be, and shall be notified of his election.

SECTION 5. An applicant for membership, on being notified of his election in writing, shall pay full membership dues for the current year and on making such payment shall be entitled to receive the entire *Bulletin* for that year. Unless payment of dues is made with thirty (30) days by those living within the continental United States and within ninety (90) days by those living elsewhere, after notice of election has been mailed, the executive committee may rescind the election of the applicant. Upon payment of dues, each applicant for membership shall be furnished with a membership card for the current year, and until such written notice and card are received, he shall in no way be considered a member of the Association.

Honorary Members

SECTION 6. The executive committee may from time to time elect as honorary members persons who have contributed distinguished service to the cause of petroleum geology. Honorary members shall not be required to pay dues.

ARTICLE IV. OFFICERS AND THEIR DUTIES

Officers

SECTION 1. The officers of the Association shall be a president, a vice-president, a secretary-treasurer, and an editor. These, together with the past-president, shall constitute the executive committee and managers of the Association.

SECTION 2. The officers shall be elected annually from the Association at large by written ballot deposited in a locked ballot box by those members, present at the annual meeting, who have paid their current dues and are otherwise qualified under the constitution. Each candidate, when voted for as a candidate for the particular office for which he is nominated, shall be thereby automatically voted for as a candidate for the executive committee for one year, except that candidates for the presidency shall be automatically voted for as candidate for the executive committee for two years.

SECTION 3. No one shall hold the office of president for two consecutive years and no

one shall hold any other office for more than two consecutive years except the editor who shall not hold office for more than six consecutive years.

Duties of Officers

SECTION 4. The president shall be the presiding officer at all meetings of the Association, shall take cognizance of the acts of the Association and of its officers, shall appoint such committees as are required for the purposes of the Association, and shall delegate members to represent the Association. He may, at his option, serve on, and may be chairman of, any committee.

SECTION 5. The vice-president shall assume the office of president in case of a vacancy from any cause in that office and shall assume the duties of president in case of the absence or disability of the latter. If the past-president shall for any reason be unable to serve as a member of the executive committee, the president shall fill the vacancy by the appointment of the next available preceding past-president.

A vacancy or disability occurring in the office of vice-president, secretary-treasurer, or editor shall be filled by majority vote of the executive committee, either for the unexpired term or for the period of disability, as the committee may decide. In the case of a tie, the president shall cast the deciding vote.

SECTION 6. The secretary-treasurer shall assume the duties of president in case of the absence of both the president and vice-president. He shall have charge of the financial affairs of the Association and shall annually submit reports as secretary-treasurer covering the fiscal year. He shall receive all funds of the Association, and, under the direction of the executive committee, shall disburse all funds of the Association. He shall cause an audit to be prepared annually by a public accountant at the expense of the Association. He shall give a bond, and shall cause to be bonded all employees to whom authority may be delegated to handle Association funds. The amount of such bonds shall be set by the executive committee and the expense shall be borne by the Association. The funds of the Association shall be disbursed by check as authorized by the executive committee.

SECTION 7. The editor shall be in charge of editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the *Bulletin* and for special publications, and, with the approval of the executive committee, may accept or reject material offered for publication. He may appoint associate, regional, and special editors.

SECTION 8. The officers shall assume the duties of their respective offices immediately after the annual meeting in which they are elected.

ARTICLE V. EXECUTIVE COMMITTEE—MEETINGS AND DUTIES

Executive Committee

SECTION 1. The executive committee shall consist of the president, past-president, vice-president, secretary-treasurer, and editor.

Meetings and Duties

SECTION 2. The executive committee shall meet immediately preceding the annual meeting and at the call of the president may hold meetings when and where thought advisable, to conduct the affairs of the Association. A joint meeting of the outgoing and incoming executive committees shall be held immediately after the close of the annual Association business meeting. Members of the executive committee may vote by proxy on matters which require a unanimous vote.

SECTION 3. The executive committee shall consider all nominations for membership and pass on the qualifications of the applicants; shall have control and management of the affairs and funds of the Association; shall determine the manner of publication and

pass on the material presented for publication; and shall designate the place of the annual meeting. They are empowered to establish a business headquarters for the Association, and to employ such persons as are needed to conduct the business of the Association. They are empowered to accept, create, and maintain special funds for publication, research, and other purposes. They are empowered to make investments of both general and special funds of the Association. Trust funds may be created, giving to the trustees appointed for such purpose, such direction as to investments as seems desirable to the executive committee to accomplish any of its objects and purposes, but no such trust funds shall be created unless they are revocable upon ninety (90) days' notice.

ARTICLE VI. MEETINGS

The Association shall hold at least one stated meeting each year, which shall be the annual meeting. This meeting shall be held in March or April at a time and place designated by the executive committee. At this meeting the election of members shall be announced, the proceedings of the preceding meeting shall be read, Association business shall be transacted, scientific papers shall be read and discussed and officers for the ensuing year shall be elected.

ARTICLE VII. AMENDMENTS

Amendments to this constitution may be proposed by a resolution of the executive committee, by a constitutional committee appointed by the president, or in writing by any ten members of the Association. All such resolutions or proposals must be submitted at the annual meeting of the business committee of the Association as provided in the by-laws, and only the business committee shall make recommendations concerning proposed constitutional changes at the annual Association business meeting. If such recommendations by the business committee shall be favorably acted on at the annual Association business meeting, the secretary-treasurer shall arrange for a ballot of the membership by mail within thirty (30) days after said annual Association business meeting, and a majority vote of the ballots received within ninety (90) days of their mailing shall be sufficient to amend. The legality of all amendments must be determined by the executive committee prior to balloting.

BY-LAWS

ARTICLE I. DUES

SECTION 1. The fiscal year of the Association shall correspond with the calendar year.

SECTION 2. The annual dues of members of the Association shall be ten dollars ($10.00). The annual dues of associates for not to exceed three years after election shall be six dollars ($6.00); for the second three-year period eight dollars ($8.00); thereafter, the annual dues of such associates shall be ten dollars ($10.00). The annual dues are payable in advance on the first day of each calendar year. A bill shall be mailed to each member and associate before January first of each year, stating the amount of the annual dues and the penalty and conditions for default in payment. Members or associates who shall fail to pay their annual dues by April first shall not receive copies of the April *Bulletin* or succeeding *Bulletins*, nor shall they be privileged to buy Association special publications at prices made to the membership, until such arrears are met.

During any period in which the United States is actually engaged in war and for a period of one year thereafter, the executive committee may at its discretion suspend, reduce, or waive annual dues to members or associate members serving in the armed forces of the United States or any allied country, without otherwise affecting their membership, except that they shall not receive the *Bulletin* during a period for which no dues are paid.

SECTION 3. On the payment of two hundred dollars ($200.00) any member in good standing shall be declared a life member and thereafter shall not be required to pay an-

nual dues. The funds derived from this source shall be placed in a permanent investment, the income from which shall be devoted to the same purposes as the regular dues.

ARTICLE II. RESIGNATION—SUSPENSION—EXPULSION

SECTION 1. Any member or associate may resign from the Association at any time. Such resignation shall be in writing and shall be accepted by the executive committee, subject to the payment of all outstanding dues and obligations of the resigning member or associate.

SECTION 2. Any member or associate who is more than a year delinquent (in arrears) in payment of dues shall be suspended from the Association. Any delinquent or suspended member or associate, at his own option, may request in writing that he be dropped from the Association and such request shall be granted by the executive committee. Any member or associate more than two years in arrears shall be dropped from the Association. The time of payment of delinquent dues for either one year or two years may be extended by unanimous vote of the executive committee.

SECTION 3. Any member or associate who resigns or is dropped under the provisions of Sections 1 and 2 of this article ceases to have any rights in the Association and ceases to incur further indebtedness to the Association.

SECTION 4. Any person who has ceased to be a member or associate under Section 1 or Section 2 of this article may be reinstated by unanimous vote of the executive committee subject to the payment of any outstanding dues and obligations which were incurred, prior to the date when he ceased to be a member or associate of the Association.

In the case of any member or associate who has been dropped between the dates of January 1, 1931, and January 1, 1936, for non-payment of dues and who shall apply for reinstatement, the executive committee is authorized, at its discretion, to accept the resignation of such member or associate effective at any date during such period of delinquency, provided, the member shall pay all indebtedness to the Association incurred prior to the date of such resignation including a proper proportion of annual dues as shall be fixed by the executive committee. Such member or associate shall not be entitled to receive the *Bulletin* for any period subsequent to the date when his resignation became effective and prior to his reinstatement.

SECTION 5. Any member or associate who, after being granted a hearing by the executive committee, shall be found guilty of a violation of the code of ethics of this Association or shall be found guilty of a violation of the established principles of professional ethics, or shall be found guilty of having made a false or misleading statement in his application for membership in the Association, may be suspended or expelled from the Association by unanimous vote of the executive committee. The decision of the executive committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

ARTICLE III. PUBLICATIONS

SECTION 1. The proceedings of the annual meeting and the papers presented at such meeting shall be published at the discretion of the executive committee in the Association *Bulletin* or in such other form as the executive committee may decide best meets the needs of the membership of the Association.

SECTION 2. The payment of annual dues for any fiscal year entitles the member or associate to receive without further charge a copy of the *Bulletin* of the Association for that year.

SECTION 3. The executive committee may authorize the printing of special publications to be financed by the Association from its general, publication, or special funds and offered for sale to members and associates in good standing at not less than cost of publication and distribution.

ARTICLE IV. REGIONAL SECTIONS, TECHNICAL DIVISIONS, AND AFFILIATED SOCIETIES

SECTION 1. Regional sections of the Association may be established provided the members of such sections are members of the Association and shall perfect an organization and make application to the executive committee. The executive committee shall submit the application to a vote at a regular annual meeting, an affirmative vote of two-thirds of the members present and voting being necessary for the establishment of such a section; and provided that the Association may revoke the charter of any regional section by a vote of two-thirds of the members present and voting at a regular annual meeting.

SECTION 2. Technical divisions may be established, provided the members interested shall perfect an organization and make application to the executive committee. The executive committee shall submit the application to a vote at a regular meeting, an affirmative vote of two-thirds of the membership present and voting being necessary for the establishment of such a division. In like manner, the Association may dissolve a division by an affirmative vote of two-thirds of the members present and voting at any annual meeting. A technical division may have its own officers, and it may have its own constitution and by-laws provided that, in the opinion of the executive committee, these do not conflict with the constitution and by-laws of the Association. The executive committee shall be empowered to make arrangements with the officers of the division for the conduct of the business of the division. A division may admit to affiliate membership in the division specially qualified persons who are not eligible to membership in the Association. Technical divisions may affiliate with other scientific societies, with the approval of the executive committee.

SECTION 3. Subject to the affirmative vote of two-thirds of the membership present and voting at an annual meeting, and with legal advice, the executive committee may arrange for the affiliation with the Association of duly organized groups or societies, which by objects, aims, constitutions, by-laws, or practice are developing the study of geology or petroleum technology. In like manner and with like advice, the executive committee may arrange conditions for dissolution of such affiliations. Affiliation with the Association need not prevent affiliation with other scientific societies. Members of affiliated societies who are not members of the Association, shall not have the privilege of advertising their affiliation with the Association on professional cards or otherwise.

ARTICLE V. DISTRICT REPRESENTATIVES

The executive committee shall cause to be elected district representatives from districts which it shall define by a local geographic grouping of the membership. Such districts shall be redesignated and redefined by the executive committee as often as seems advisable. Each district shall be entitled to one representative for each seventy-five members, but this shall not deprive any designated district of at least one representative. The representatives so apportioned shall be chosen from the membership of the district by a written ballot arranged by the executive committee. They shall hold office for two years, their term of office expiring at the close of the annual meeting.

ARTICLE VI. COMMITTEES

Appointment and Tenure

SECTION 1. There shall be the following standing committeees: business committee; research committee; committee on geologic names and correlations; committee on applications of geology; committee for publication; finance committee; trustees of revolving publication fund; trustees of research fund; and medal award committee.

The president shall appoint all standing committees except the business committee and the medal award committee, for which provision is hereafter made. Members of all

committees except the business committee shall serve for a three-year term, but in rotation, with one-third of the members being appointed each year. The president shall designate the chairmen, annually, shall have power to fill vacancies, and shall notify the members of the committees of their appointment. The president may designate one or more vice-chairmen annually.

In addition to the aforesaid standing committees, the president shall appoint annually or semiannually a resolutions committee, and such special committees as the executive committee may authorize. Special committees shall be appointed for a term of one year. The president shall designate the chairmen of such committees.

Business Committee

SECTION 2. The business committee shall act as a council and advisory board to the executive committee and the Association. This committee shall consist of the executive committee, not more than five members at large appointed annually by the president, two members elected by and from each technical division, and the district representatives. The president shall also appoint annually a chairman and a vice-chairman, but neither of these need be one of those otherwise constituting the business committee. The secretary-treasurer shall act as secretary of the business committee. If a district or technical representative is unable to be present at any meeting of the committee he may designate an alternate, who, in the case of a district representative, may or may not be a resident of the district he is asked to represent, and the alternate, on presentation of such a designation in writing, shall have the same powers and privileges as a regularly chosen representative. The business committee shall meet the day before the annual meeting at which all proposed changes in the constitution or by-laws shall be considered, all old and new business shall be discussed, and recommendations shall be voted for presentation at the annual meeting.

Research Committee

SECTION 3. The purpose of the research committee is the advancement of research, particularly within the field of petroleum geology. The committee shall consist of twenty-four members unless a different number is authorized by the executive committee.

Committee on Geologic Names and Correlations

SECTION 4. The purpose of the committee on geologic names and correlations is to lend assistance to authors on problems on stratigraphy and nomenclature and to advise the editor and executive committee in regard to the propriety of the use of stratigraphic names and correlations in papers submitted for publication by the Association. The committee shall consist of fifteen members unless a different number is authorized by the executive committee.

Committee on Applications of Geology

SECTION 5. The object of the committee on applications of geology is to advise and promote ways and means for informing the general public on all phases of geology particularly on the natural occurrence of oil and gas underground, the methods of searching for these substances, and the methods of exploiting them. The committee shall consist of twelve members unless a different number is authorized by the executive committee.

Committee for Publication

SECTION 6. The purpose of the committee for publication is to assist in securing desirable manuscripts for publication in the *Bulletin* or other publications of the Association. The committee may also assist in securing papers for delivery at the annual meetings. The committee shall consist of twenty-four members unless a different number is authorized by the executive committee.

Finance Committee

SECTION 7. The finance committee shall act as financial advisers to the executive committee. The committee shall consist of three members. If a member of the finance committee should be elected to the executive committee he shall resign from the finance committee and the president shall appoint a member of the Association to complete his unexpired term.

Trustees of Revolving Publication Fund

SECTION 8. Before any publication project shall be undertaken with the use of the revolving publication fund the approval of the trustees and the executive committee must be secured. There shall be three trustees. If a trustee should be elected to the executive committee he shall resign as a trustee and the president shall appoint a member of the Association to complete his unexpired term.

Trustees of Research Fund

SECTION 9. Before any research work may be undertaken with the use of money from the research fund, the approval of the trustees and the executive committee shall be secured. There shall be three trustees. If a trustee shall be elected to the executive committee he shall resign as a trustee and the president shall appoint a member of the Association to complete his unexpired term.

Resolutions Committee

SECTION 10. The resolutions committee shall be charged with the duty of presenting at the annual and semi-annual meetings resolutions expressing the Association's appreciation and thanks to those who have worked and contributed to the success of the meetings.

Medal Award Committee

SECTION 11. The purpose of the committee shall be to choose recipients for all medals or other awards which may be established by the executive committee. The committee shall consist of nine members and three ex-officio members. The nine members of the original committee shall be appointed by the president, three of whom shall serve for three years, three for two years, and three for one year. One of each of the groups appointed for the different lengths of time shall be a former president of the Association. Each incoming president shall thereafter appoint three members of the committee to serve for three years, one of which shall be a former president of the Association. Vacancies on the committee due to resignation or other causes shall be immediately filled by the president. The ex-officio members shall be: (1) the president of the Association, (2) the president of the Society of Exploration Geophysicists, (3) the president of the Society of Economic Paleontologists and Mineralogists. The president of the Association shall be the chairman of the committee unless he shall, at his election, name a chairman to serve for one year.

ARTICLE VII. AMENDMENTS

These by-laws may be amended by vote of three-fourths of the members present and voting at any annual meeting, provided that such changes shall have been recommended to the meeting by the business committee and provided that their legality shall be determined by the executive committee prior to publication.

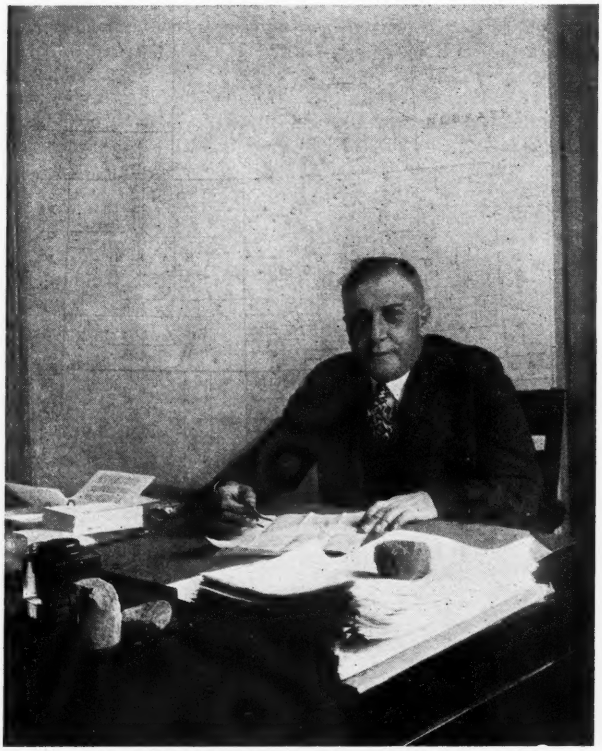
BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 9 (SEPTEMBER, 1944), PP. 1413-1414, 1 FIG.

MEMORIAL

CECIL EARL SHOENFELT

(1885–1944)

Cecil Earl Shoenfelt was born in Norway, Michigan, on February 7, 1885, and died on April 17, 1944, in Denver, Colorado. While he had not been in good health for some time, his sudden death was a great shock to his family and friends.



CECIL EARL SHOENFELT

A great part of his early life was spent in Muskogee, Oklahoma, where his father, Colonel J. Blair Shoenfelt, was the Indian Agent. Earl was a student at Henry Kendall College, Wentworth Military Academy, Kimball Academy, and Dartmouth, and completed his scholastic work by extension at Chicago University. His marriage to Miss Jean Dalton took place on September 15, 1908, and she survives him.

His keen interest in the oil industry took him during the years to most of the oil centers in the United States. He and his father at one time were independent operators and participated in the early development of the famous Glen pool. On March 15, 1929, he established Petroleum Information, Inc., at Denver and from then on this service absorbed his time and attention. Its increasing demands were met willingly and under his guidance it grew into a real and valuable source of petroleum information for the industry.

Earl's vacations were generally spent camping and fishing, at times on the Gulf Coast, but generally in some little known spot in the Rocky Mountains. Love for his Petroleum Information service, however, cut many of these vacations all too short.

In 1928 his membership in American Association of Petroleum Geologists was sponsored by his friends, F. B. Plummer, A. E. Brainerd, and R. L. Heaton. He was also a member of the American Institute of Mining and Metallurgical Engineers, and from 1934 to 1944 he wrote the article on production for Colorado for the Petroleum Division of A.I.M.E. yearly publication. Of his many contributions to the oil industry, an outstanding one was his annual report of Rocky Mountain activities. He had just completed compiling and editing the data for 1943 at the time of his death.

Earl was friendly to all, always kind and considerate and ready to help, even when during the last months it took a great toll of his strength. His close business associates and friends will miss him, and so will the industry. One of Nature's gentlemen has left us for a time.

A. E. Brainerd

Continental Oil Company
Denver, Colorado
July 13, 1944

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 9 (SEPTEMBER, 1944), PP. 1415-1416

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

LEWIS B. KELLUM, associate professor of geology at the University of Michigan, is directing the program of petroleum exploration on the Alaska Peninsula this summer for the United States Geological Survey. His address is in care of the Survey, Post Office Box 560, Anchorage, Alaska.

At a regular meeting of the Mississippi Geological Society, May 31, the following officers were elected to serve for the year beginning June 1: L. R. MCFARLAND, Magnolia Petroleum Company, president; J. B. STOREY, Union Producing Company, vice-president; FREDERIC F. MELLEN, British-American Oil Producing Company, secretary-treasurer, 1007 Tower Building, Jackson, Mississippi.

MAX W. BALL returned to his office in Denver, Colorado, in August, after 8 months on a consulting job in Michigan. Early in September he left for Washington to take up his duties with the Petroleum Administration for War, to which he was appointed.

W. E. WALLACE, JR., head of the geological department at Centenary College of Louisiana, is now on leave with the Sohio Petroleum Company, Shreveport.

EDWARD L. TULLIS is on short leave of absence from the South Dakota School of Mines and Technology and is doing geological work in Cape Breton Island for the Richmond Petroleum Company and the Sydney Petroleum Company.

JAMES D. AIMER, formerly East Texas district geologist for the Arkansas Natural Gas Corporation, has accepted a position as district geologist for East Texas and North Louisiana with the Barnsdall Oil Company, and is headquartered in Shreveport.

Major HUBERT G. SCHENCK, after tours of duty at Fort Custer, Michigan, the University of Chicago, and the Presidio of Monterey, is now stationed at Harvard University.

Lieutenant Colonel B. COLEMAN RENICK, 219 Park Hill Drive, San Antonio, Texas, recently chief of civilian personnel and director of manpower, Headquarters, San Antonio Air Service Command, Kelley Field, is now on an inactive status and has returned to professional geological work. He expects to devote most of his time to Mississippi geology.

GLENN SCOTT DILLE, who has been a practicing consultant for several years, has been appointed manager of the land and geological department of the Deep Rock Oil Corporation, Tulsa.

WARREN B. WEEKS, vice-president of the A.A.P.G., has been transferred from Shreveport, Louisiana, to Bartlesville, Oklahoma, by the Phillips Petroleum Company. His new office is that of division geologist for West Texas and New Mexico. JOSEPH PURZER remains at Shreveport as district geologist for East Texas, South Arkansas, and North Louisiana. CARL E. MOSES is transferred from Quincy, Florida, to Jackson, Mississippi, as district geologist for Mississippi, Alabama, Florida, and Georgia.

OLIVER B. HOPKINS has been advanced from the position of chief geologist to that of vice-president in charge of producing operations of Imperial Oil Limited, Toronto, Canada. He is succeeded by O. C. WHEELER, recently assistant chief geologist.

HAROLD F. MOSES, manager of exploration for the Carter Oil Company since 1941, has been elected a vice-president and is head of exploration and research for the company.

Lieutenant Colonel FRANK E. HORNKOHL, operator of the Hornkohl Laboratories in Bakersfield, California, is executive officer of the Herington Army Air Field, Herington, Kansas.

THEODORE A. LINK, geologist for many years with Imperial Oil Limited, at Calgary, Alberta, has moved to Toronto to become assistant chief geologist for his company. He is succeeded at Calgary by J. B. WEBB, formerly with the Anglo Canadian Oil Company.

On August 27, 1859, 85 years ago, the Drake well was brought in on Oil Creek near Titusville, Pennsylvania. This date is considered the birthday of the American petroleum industry.

WILLIAM J. MILLARD is in Brazil where he has been working on production of strategic minerals for 2 years. He may be addressed in care of the United States Embassy.

HUGH MCCLELLAN is district geologist for the Continental Oil Company, in the Los Angeles Basin. His address is 700 Edison Building, Los Angeles 13, California.

FREDERICK J. SMITH, who has been with the Tennessee Valley Authority in connection with the Hales Bar Dam project, is now employed as geologist by the Sinclair Wyoming Oil Company, Evansville, Indiana.

Major BEN B. COX, recently with the Arctic, Desert, and Tropic Information Center in New York City, is now situated at 56 West 36th Street, New York, New York.

THOMAS J. NEWBILL, recently with the Standard Oil Company of California, is employed by the Richmond Petroleum Company of Colombia, Bogota, Colombia.

WALTER K. LINK is manager for the foreign Western Hemisphere exploration of the Standard Oil Company of New Jersey, in areas where the Standard has no operating company.

MORRIS B. WHITE has left the Kerlyn Oil Company, Oklahoma City, to become district engineer for the Sunray Oil Corporation. His address is Box 278, Allen, Oklahoma.

RALPH E. TAYLOR, formerly with the Freeport Sulphur Company, New Orleans, may be addressed in care of W. R. Lindsay, mining engineer, 302 Bay Street, Toronto 1, Ontario, Canada.

R. M. SWESNIK, formerly with the Sun Oil Company at Tallahassee, Florida, is with the Gulf Oil Corporation, Apco Tower, Oklahoma City, Oklahoma.

M. M. VALERIUS, consulting geologist, may be addressed at 648 Ratcliff Street, Shreveport, Louisiana.

SAMUEL A. GROGAN died at Houston, Texas, aged 54 years. Formerly chief geologist for the Gulf Oil Corporation in Mexico, he had been with that company in geological work for 31 years.

DAVID J. FLESH has been with the Armed Services on overseas duty for more than 2 years. He has returned to the United States and has been given reserve status to carry on the practice of his profession. He specializes in reports, appraisals, and oil and gas properties, at 711 City Bank Building, Shreveport, Louisiana.

LEE HAGER, for many years a consulting geologist at Houston, Texas, died on August 12. He was president of the Federal Royalty Company.

JOHN H. MELVIN is treasurer and geologist of the Pennsylvania Drilling Company, Pittsburgh, Pennsylvania. He was visiting company operations in the southwest in August, temporarily at Carlsbad, New Mexico.

W. F. BEUCK has left the staff of the International Petroleum Company in Ecuador and is now on the geological staff of the Carter Oil Company at Seminole, Oklahoma.

LUTHER C. SNIDER, past-president and past-editor of the Association, and professor of geology at the University of Texas, is recuperating at Austin, after a hospital experience at Rochester, Minnesota.

WILLIAM G. KANE has been in Mexico since the beginning of the war, first with the Board of Economic Warfare-Metals Reserve Company and more recently with the Foreign Economic Administration-United States Commercial Company.

Major JOHN D. TODD, after 3½ years of service with the Army Air Forces, has reverted to inactive status. At the time of entering the service, he was a member of the firm of Roper and Todd, Houston, Texas. He plans to reenter the consulting field.

EDMUND M. SPIEKER has been appointed chairman of the department of geology at the Ohio State University, Columbus. Spieker is on leave from the University for the remainder of this year to take charge of a petroleum project in Alaska for the United States Geological Survey.

PROFESSIONAL DIRECTORY

CALIFORNIA

COLORADO

COLORADO

ILLINOIS

ILLINOIS

TEXAS

EAST TEXAS GEOLOGICAL SOCIETY

TYLER, TEXAS

President - - - - - - - - - G. J. Loetterle
Shell Oil Company, Inc., Box 2037

Vice-President - - - - - - - - B. W. Allen
Gulf Oil Corporation

Secretary-Treasurer - - - - - - L. L. Harden
Sinclair Prairie Oil Company, Box 1110

Executive Committee - - - - J. H. McGuirt
Magnolia Petroleum Company

Meetings: Monthly and by call.
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel

HOUSTON GEOLOGICAL SOCIETY

HOUSTON, TEXAS

President - - - - - - - - - Leslie Bowling
Union Oil Company of California

Vice-President - - - - - W. B. Milton, Jr.
Gulf Oil Corporation

Secretary - - - - - - - - - - W. B. Moore
Atlantic Refining Company, Box 1346

Treasurer - - - - - - - - - - G. J. Smith
Pan American Producing Company

Regular meeting held the first and third Thursdays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

SOUTH TEXAS GEOLOGICAL SOCIETY

SAN ANTONIO, TEXAS

President - - - - - - - Robert N. Kolm
Atlantic Refining Co., 1742 Milam Building

Vice-President - - - - - Donald O. Chapell
Transwestern Oil Co., 1600 Milam Building

Secretary-Treasurer - - - Robert D. Mebane
Saltmount Oil Co., 916 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY

CHARLESTON, WEST VIRGINIA
P. O. Box 2385

President - - - - - - - - Douglas Rogers, Jr.
South Penn Natural Gas Company, Parkersburg

Vice-President - - - - - - Veleair C. Smith
Kanawha Valley Bank Building

Secretary-Treasurer - - - - - - Charles E. Stout
United Fuel Gas Company, Box 1273

Editor - - - - - - - - - H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., Box 1473

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

FORT WORTH GEOLOGICAL SOCIETY

FORT WORTH, TEXAS

President - - - - - Joseph H. Markley, Jr.
The Texas Company, Box 1720

Vice-President - - - - - - James L. Morris
The Pure Oil Company, Box 2107

Secretary-Treasurer - - - Spencer R. Normand
Independent Exploration Company
2210 Ft. Worth Natl. Bank Bldg.

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

NORTH TEXAS GEOLOGICAL SOCIETY

WICHITA FALLS, TEXAS

President - - - - - - - - - Donald Kelly
The Texas Company

Vice-President - - - William Lloyd Haseltine
Magnolia Petroleum Co., Box 239

Secretary-Treasurer - - - David T. Richards
Shell Oil Co., Inc., Box 2010

Luncheons and evening programs will be announced.

WEST TEXAS GEOLOGICAL SOCIETY

MIDLAND, TEXAS

President - - - - - - - - Robert I. Dickey
Forest Development Corporation

Vice-President - - - - - George R. Gibson
Richfield Oil Corporation

Secretary-Treasurer - - - - - - - Jane Ferrell
Magnolia Petroleum Company, Box 633

Meetings will be announced

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - William M. Rust, Jr.
Humble Oil & Refining Company, Houston, Texas

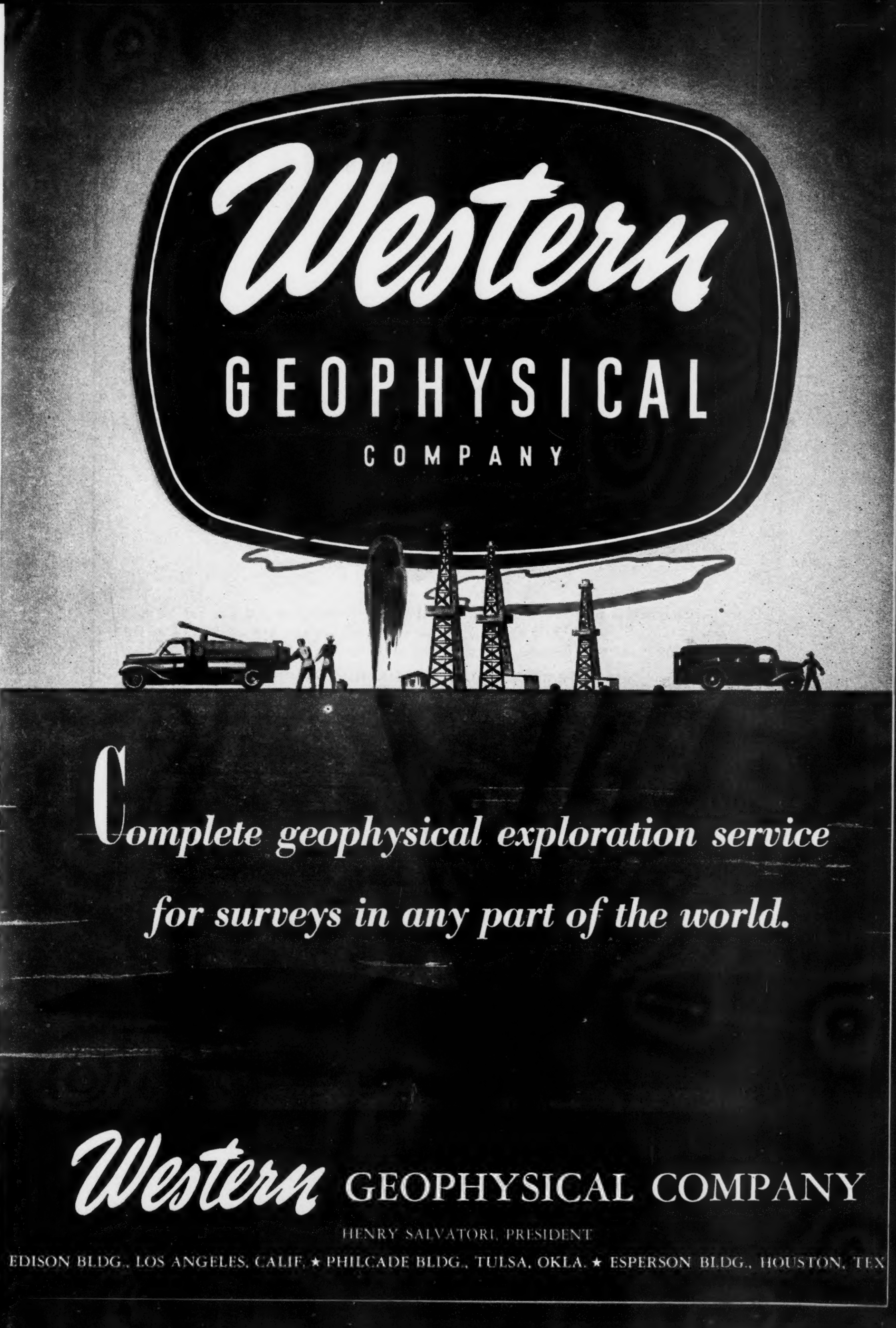
Vice-President - - - - - - - Henry C. Cortes
Magnolia Petroleum Company, Dallas, Texas

Editor - - - - - - - - - Joseph A. Sharpe
Stanolind Oil and Gas Company, Tulsa, Oklahoma

Secretary-Treasurer - - - - W. Harlan Taylor
Petty Geophysical Engineering Company
1449 Esperson Bldg., Houston, Texas

Past-President - - - - - - - R. D. Wyckoff
Gulf Research and Development Company
Pittsburgh, Pennsylvania

Business Manager - - - - - - J. F. Gallie
P.O. Box 410, El Dorado, Arkansas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Western GEOPHYSICAL COMPANY
HENRY SALVATORI, PRESIDENT
EDISON BLDG., LOS ANGELES, CALIF. ★ PHILCADE BLDG., TULSA, OKLA. ★ ESPERSON BLDG., HOUSTON, TEX

AVAILABLE PUBLICATIONS OF

The American Association of Petroleum Geologists

Box 979, Tulsa 1, Oklahoma

1931 **Geologic Map of Cuba.** Compiled by J. Whitney Lewis. Folded paper sheet, 24 x 10 inches. Scale, 3/16 inch = 10 miles. Geologic column on same sheet. From Lewis' "Geology of Cuba" (out of print), in June, 1932, *Bulletin.* Map per copy .... $ .25

1935 **Geology of Natural Gas.** Symposium on occurrence and geology of natural gas in North America. By many authors. 1,227 pp., 250 illus. 6 x 9 inches. Cloth. **To members and associates, $4.50** 6.00

1936 **Geology of the Tampico Region, Mexico.** By John M. Muir. 280 pp., 15 half-tone plates, 41 line drawings, 9 tables. 6 x 9 inches. Cloth. **To members and associates, $3.50** 4.50

1936 **Gulf Coast Oil Fields.** Symposium on Gulf Coast Cenozoic. By 52 authors. Chiefly papers reprinted from the Association *Bulletin* of 1933-1936 gathered into one book. xxii and 1,070 pp., 292 figs., 19 half-tone pls. 6 x 9 inches. Cloth. **To members and associates, $3.00** 4.00

1936 **Areal and Tectonic Map of Southern California.** By R. D. Reed and J. S. Hollister. In 10 colors. From "Structural Evolution of Southern California," December, 1936, *Bulletin.* Scale, 1/8 inch = 1 mile. Map and 4 structure sections on strong ledger paper, 27 x 31 inches, rolled in mailing tube .... .50

1938 **Miocene Stratigraphy of California.** By Robert M. Kleinpell. 450 pp.; 14 line drawings, including a large correlation chart; 22 full-tone plates of foraminifera; 18 tables (check lists and a range chart of 15 pages). 6 x 9 inches. Cloth. **To members and associates, $4.50** 5.00

1941 **Stratigraphic Type Oil Fields.** Symposium of 37 papers by 52 authors. 902 pp., 300 illus., 227 references in annotated bibliography. 6 x 9 inches. Cloth. **To members and associates, $4.50** 5.50

1942 **Source Beds of Petroleum.** By Parker D. Trask and H. Whitman Patnode. Report of investigation supported jointly by the American Petroleum Institute and the Geological Survey of the United States Department of the Interior from 1931 to 1941. 566 pp., 72 figs., 151 tables. 6 x 9 inches. Cloth. **To members and associates, $3.50** 4.50

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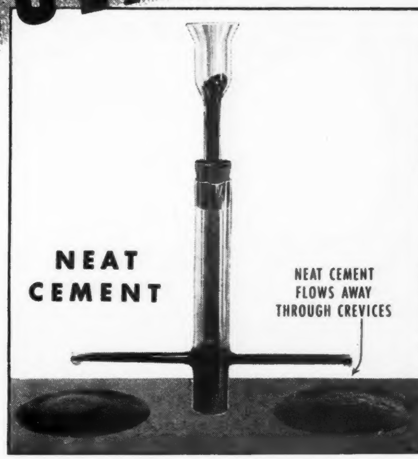

The apparatus above represents a well drilled into a badly fractured or creviced zone (glass-tubing cross arms represent crevices), the funnel tubing being the "casing." Neat cement on being poured down the funnel tube fills the bottom of the glass "hole" and flows out of the tubing. It continues to flow out of the tubing while slurry is added to the funnel. Note flat angle of repose. This demonstrates why large crevices are difficult or impossible to seal with neat cement.

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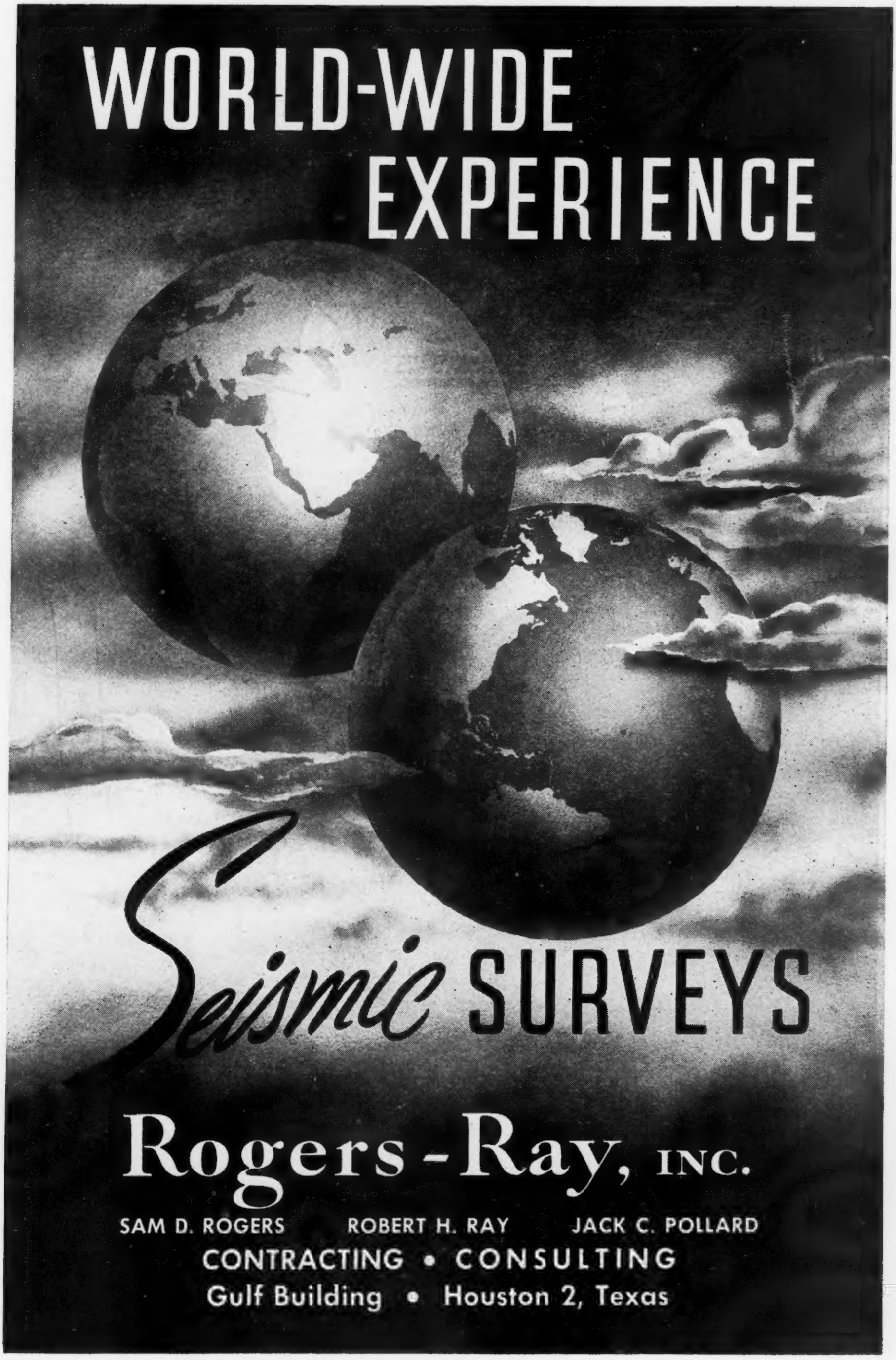

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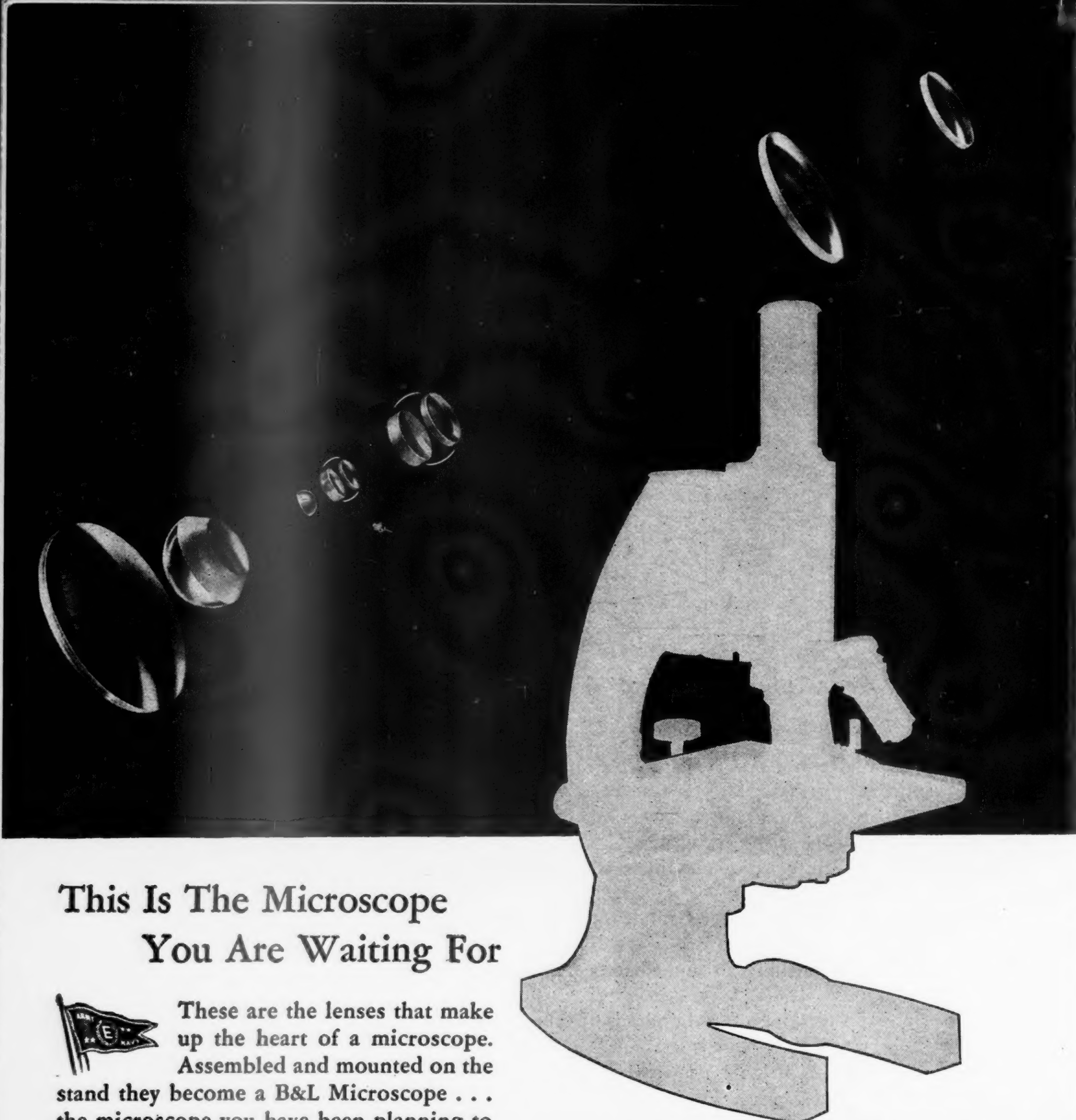

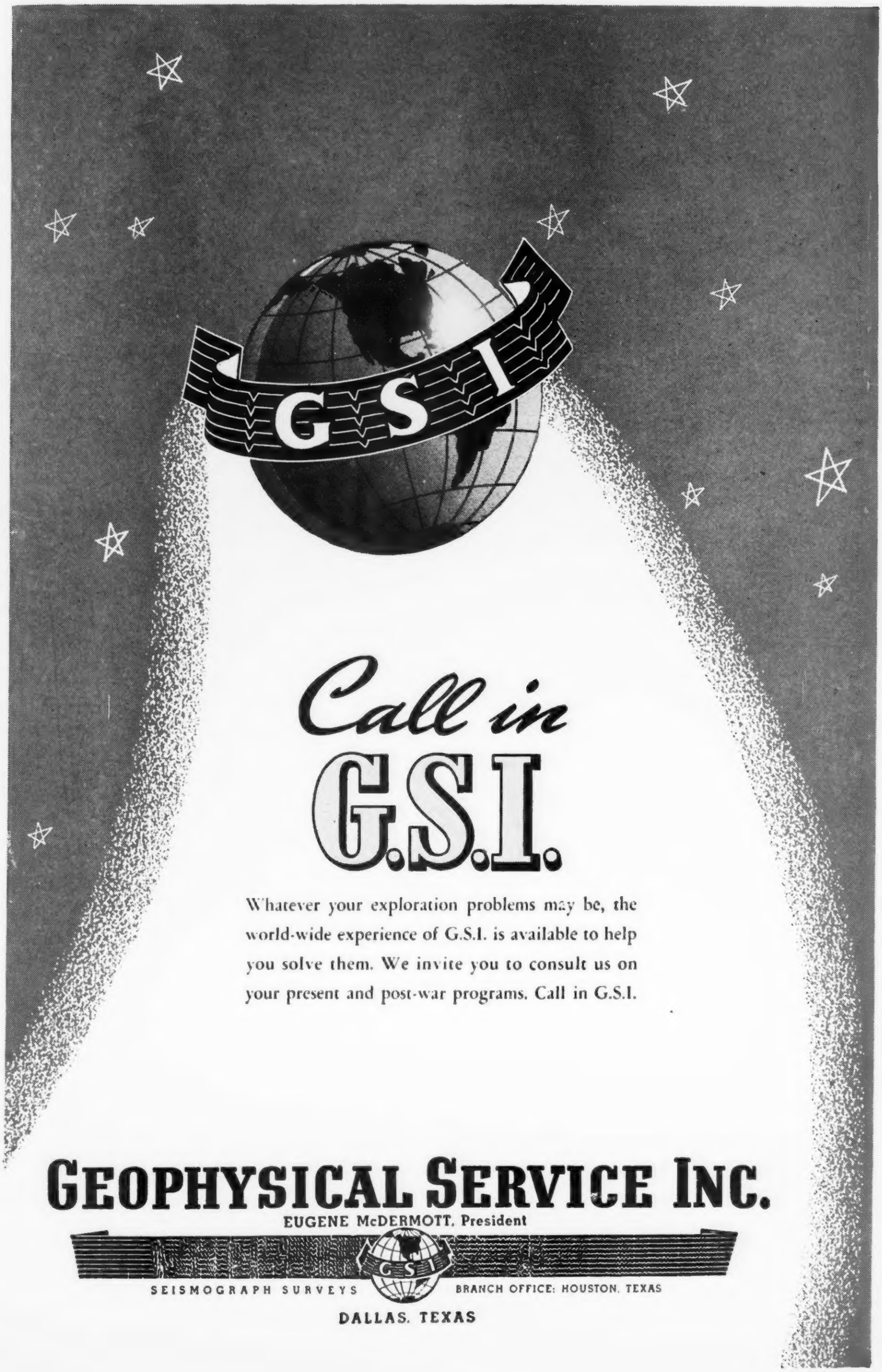
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